OCTOBER 1960

NUCLEONICS

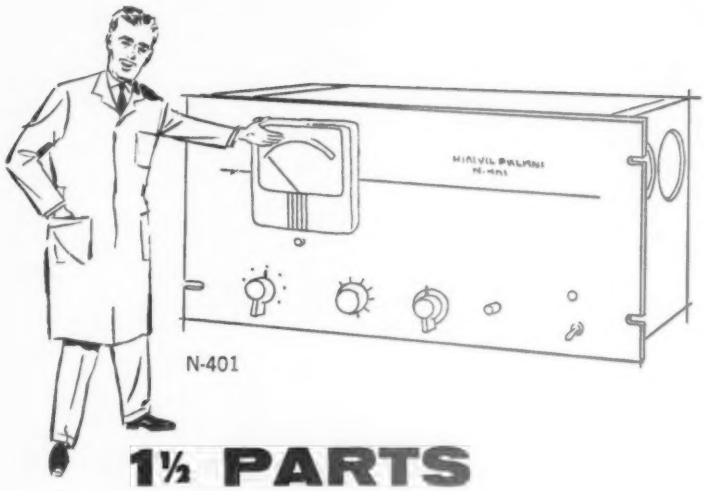
APPLIED RADIATION • ATOMIC POWER • NUCLEAR ENGINEERING

NUCLEAR CANADA ISSUE

Pursuing a vigorous and independent tradition the Canadians have evolved a nuclear program of such solidity and engineering enterprise that **NUCLEONICS** devotes to it this entire issue.

See page 3

A McGraw-Hill Publication • One Dollar



N-401

1½ PARTS PER MILLION LONG TERM STABILITY*

In Hamner's N-401 High Voltage Power Supply, stability is unexcelled, yet its measurement for the purpose of laying down specifications posed a great problem. The measurement was made by a leading university noted for their precision measurements of atomic constants by X-ray methods. The results obtained indicated a basic long term stability of *approximately 1½ parts per million per day — actually more stable than batteries. In the experiment, resistances used to attenuate the N-401's output had been aged and their values studied for over 50 years. Temperature was held constant to within .05°C.

Voltage: 500-1800 V, dual polarity
Current: 0-5 ma
Noise and Ripple: Less than 1 mv rms at full output

The N-401 has been designed for use in scintillation and proportional counting systems, where other systems' components offer the same degree of stability.

Some of Hamner's other instruments are described at the right. Each instrument has been designed to operate as an independent unit or in a system with other Hamner instruments.

Hamner

Hamner Electronics Co., Inc.

Department 10, P. O. Box 531, Princeton, New Jersey
PEnnington 7-1320

N-357 ULTRA LOW-NOISE PREAMPLIFIER

This unit has been designed especially for use with Solid State Detectors. The performance of this instrument is unexcelled in providing a high S/N ratio.

Gain: 100
Risetime: 0.25 μs
Input Capacity: Approx. 20 mmf
Equivalent Input Noise: 20 μv peak to peak
Output Pulse Shape: negative, noise to 2.5 volts, 7 μs RC decay
Output Impedance: 100 ohms

The preamplifier incorporates an adjustable bias supply for the solid state detector. Pulse shaping has been selected for optimum S/N ratio and to match the input requirements of Hamner's N-300 series amplifiers. The latter units will also provide suitable B+ and filament voltages for the N-357.

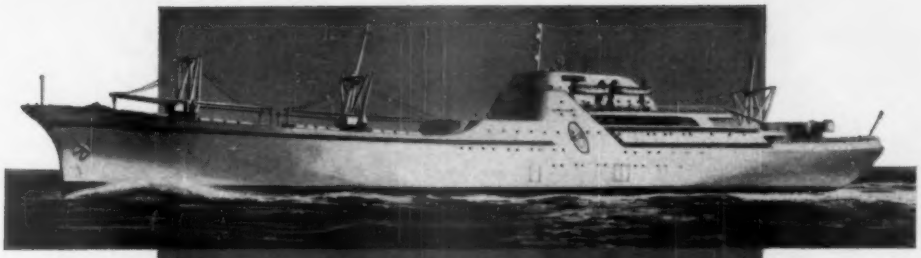
The N-357 is available from stock at a price of $300.00 FOB Princeton, New Jersey.

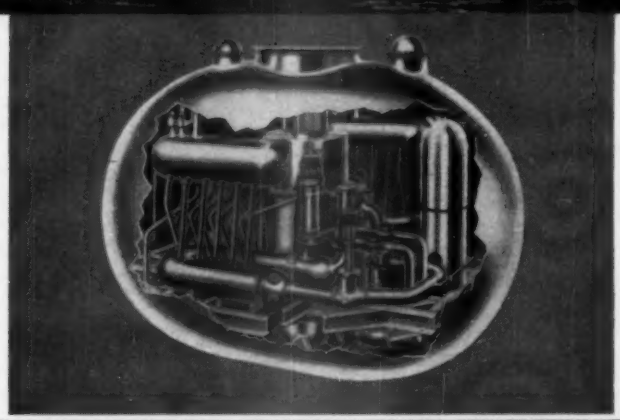
Automatic Data Handling with High-Speed Scaler and Crystal-Controlled Electronic Timer

Operating Modes

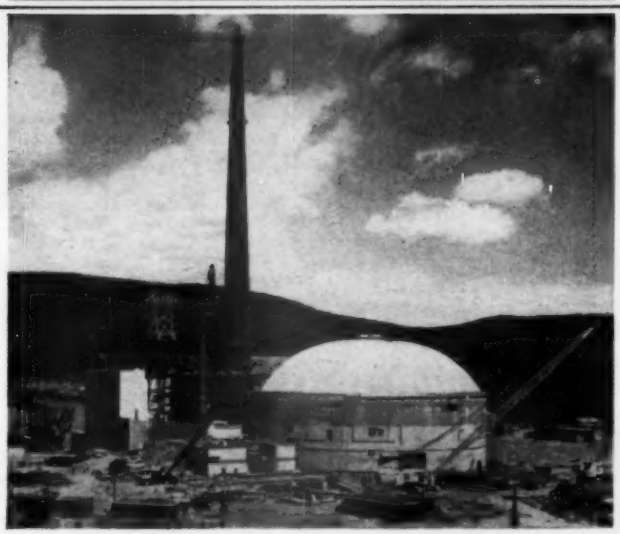
- **Preset Count:** 15 settings from 10 to 500,000 counts.
- **Preset Time:** 15 settings from 0.1 to 50,000 seconds.
- **Combined Preset Time & Count:** Any of the time or count settings may be used simultaneously with the system stopping when the first preset event occurs.
- **Data Print-Out:** Both scaler and timer provide "staircase" outputs. Time, counts, or both may be printed out or code punched on cards or tape.
- **Automatic Recycling:** The system will recycle automatically, if desired, following occurrence of a preset event and data print-out. In this case, print-out can be cumulative or destructive. Both print-out and automatic recycling can be used in any mode of operation.

These units are not only highly flexible but are also of the fine research quality typical of all Hamner Instruments. Scaler and Timer may be used together to provide the operational modes listed above. They may also be used independently.





N. S. SAVANNAH . . . forerunner of a nuclear-powered merchant fleet, the Savannah's Pressurized Water Reactor (shown) was designed and fabricated by Babcock & Wilcox.



INDIAN POINT POWER STATION, Consolidated Edison Co., to serve New York City. Pressurized Water Thorium Uranium Converter Reactor, 163 MW (with an additional 112 MW generated from fossil fuel). This Reactor was also designed and fabricated by B&W

Major experience with the Pressurized Water Reactor system has provided The Babcock & Wilcox Company with important data in the search for economic application of nuclear energy.

CONTINUING THEIR LEADERSHIP IN NUCLEAR RESEARCH AND DEVELOPMENT, B&W IS NOW READY TO DISCUSS AN ADVANCED CONCEPT FOR POWER REACTOR DESIGN . . . ONE THAT WILL DEMONSTRATE MARKED REDUCTIONS IN FUEL AND CAPITAL COSTS FOR NUCLEAR POWER STATIONS.

The Babcock & Wilcox Company, 161 E. 42nd Street, New York 17, N. Y., U.S.A.

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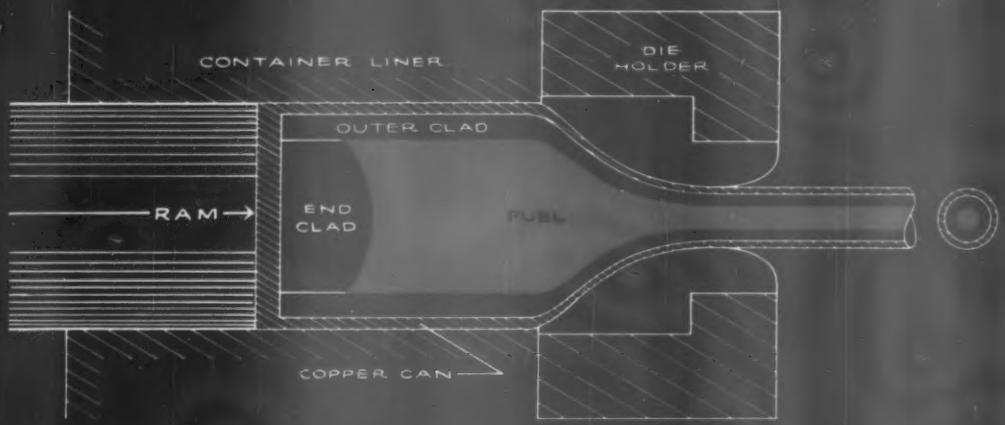
B&W THE BABCOCK & WILCOX COMPANY

NUCLEAR POWER APPLICATIONS

Complete nuclear systems, cores, components, fuel elements, nuclear research and development



M & C Nuclear — Largest Producer of Co-extruded Fuel

No idle claim this — M&C Nuclear has fabricated more clad pins, plates, wire, rod and tubing by this technique than any other supplier.

Three complete reactor loadings of co-extruded elements made by M&C Nuclear are in operation — and two additional loadings are now being made as a *re-order*.

Until recently, elements clad by co-extrusion were laboratory curiosities — now at M&C Nuclear they are being manufactured on a *production basis*.

We co-extrude tubular uranium aluminum elements of the CP-5 type; plate type cermet elements; alloy elements of uranium with zirconium, niobium and molybdenum as pins, tubes or rods. We can offer wire fuel elements up to 50 feet in length.

The advanced state of co-extrusion technology at M&C Nuclear enables us to offer a high degree of dimensional control, reproducibility, and quality assurance. Complete facilities are available for testing and certification by destructive and non-destructive techniques.

It might well be of importance for you to consider this at an early stage of your next reactor project.

TEXAS INSTRUMENTS
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NUCLEONICS

APPLIED RADIATION • ATOMIC POWER • NUCLEAR ENGINEERING

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...about NUCLEONICS

Something Unusual

We have done something unusual in this issue of NUCLEONICS: we have devoted it entirely to contributions from one country, Canada. We do this out of the conviction, explained in more detail on page 51, that nuclear activities in Canada are too significant to ignore and yet too little known by the U. S. nuclear community at least.

This issue was first conceived during a NUCLEONICS dinner discussion on The Outlook for Competitive Nuclear Power (NU Jan. '60, p. 68). Among the participants was W. B. Lewis, Vice-President for Research and Development of Atomic Energy of Canada Ltd. We were struck by Lewis' confident prediction of achieving economic nuclear power in Canada and his competent discussion of the problems that had to be resolved. This issue grew directly out of those impressions—supplemented by a lot of hard work, trips between New York and Chalk River, and the wholehearted cooperation of dozens of nuclear experts in Canada.

W. B. LEWIS. In things nuclear he speaks for Canada. (Here at Geneva–1958.)

What sort of man is it who caught our editorial attention so? Wilfrid Bennett Lewis, 52, has directed atomic energy research in Canada since 1946. Lewis had spent the war years in Britain doing radar research, but such was his reputation as a physicist (PhD from Cambridge in 1934) that John Cockcroft recommended him as his successor upon retiring as director of Canada's wartime research to head up Harwell. (Cockcroft and Lewis had studied together under Rutherford at the Cavendish, shared radar work during the war.)

A bachelor, Lewis brings a commitment to his work that is startling even in the nuclear field. The guards at Chalk River say that no man spends more time on the project than he, and Lewis, who used to be a regular contender (and loser) in the Y-Flyer races conducted by the Deep River Yacht Club, hasn't been able to get his boat in the water for the past three years. But more than time, Lewis brings to his job a remarkable depth and understanding that causes him to be able to comment effectively on almost all of the technical work done under him. Authors of Chalk River technical papers can count on detailed criticism from "W. B."—who'll wade in fearlessly in any field.

Lewis has a command of the Canadian program that borders on omniscience. A prolific (and able) writer, he is Canada's prime technical spokesman in the nuclear field.

Canada's nuclear power program is fast growing too big to be contained within one man's grasp, and yet when nuclear power becomes economic in Canada there will be few who will dispute that it was this man's brainchild.

A McGRAW-HILL PUBLICATION

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DEPARTMENT A-10

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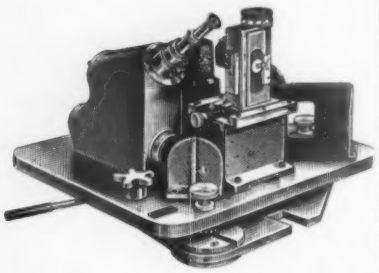
DAVISON CHEMICAL DIVISION

ERWIN, TENNESSEE

OPTICAL STRAIN-MEASURING INSTRUMENT



Tests tensile properties of radioactive materials at reactor temperatures

This Optical Strain-Measuring Instrument was designed for nuclear reactor development work. It permits precise determination of the tensile properties of irradiated fuel and structural materials at reactor temperatures.

Gaertner Scientific Corporation, designers of the instrument, had this problem to overcome: extremely accurate measurement of elongation must be made even when the specimen itself is inaccessible due to radiation and temperatures up to 800° C.

To solve the problem, Gaertner developed a special mechanical-optical system to measure elongation of a specimen with direct reading to 50 micro-inches.

The optical system has a working distance of more than 24 inches, permitting the insertion of shielding between the optical unit and the furnace . . . the light travels through six inches of lead-glass shielding and the quartz window of the furnace. This allows the operator to observe the specimen closely and yet be completely safe from radiation hazard.

Wide range measurement is possible . . . the micrometer moves through 0.5 inches for a one-inch specimen. This makes it possible to measure elongation-to-failure of many irradiated fuels and structural materials.

The Optical Strain-Measuring Instrument is one of *many* precision optical instruments designed and manufactured by Gaertner to measure dimensional changes of specimens under various environmental conditions.

Write for Bulletin 161

Gaertner SCIENTIFIC CORPORATION 1257 Wrightwood Ave. Chicago 14, Illinois

NUCLEAR REACTIONS

UO_2 Additives

DEAR SIR:

We have previously reported (NU, Nov., 1959, p. 156; H. Shapiro, R. M. Powers, SCNC-294, Oct., 1959) that increasing amounts of Y_2O_3 (1 and 4 mol percent) added to UO_2 increase the thermal conductivity of UO_2.

Subsequent work has failed to confirm the original results and, in fact, has shown that 3.85 m/o additions of Y_2O_3, while somewhat increasing electronic-carrier content, reduce the thermal conductivity of UO_2. The recent results have been obtained by additional measurements on the Kingery longitudinal heat-flow apparatus by Y. Cavallaro as well as by in-pile thermal-conductivity measurements.

In tests of three identical stoichiometric UO_2 samples, the original criteria for balance in the Kingery apparatus were found to be in error. A stepped temperature profile along the guard heater, which was shown to be present when additional thermocouples were inserted, apparently permitted heat losses of appreciable size to occur even when balances of guard and sample to within $\pm 1°$ C were obtained at four points along the samples.

Because of difficulties in these measurements, parallel determinations of thermal conductivity were carried out in the hydraulic-rabbit facility at Chalk River, Ontario, under the direction of J. A. L. Robertson and A. Bain. Duplicate samples were prepared at Sylcor of $UO_{2.00}$ and $UO_{2.09}$ containing 3.85 m/o Y_2O_3. The enrichments were adjusted to give comparable heat ratings in all samples. The grain sizes of doped and undoped samples were comparable as were theoretical densities (95% and 97% theoretical, respectively), and both were prepared by comparable sintering methods (sintering of oxide containing excess oxygen as sintering aid at 1,300° C in argon followed by reduction in an argon-hydrogen mixture). Somewhat higher porosity was noticeable in the metallography of the Y_2O_3-doped samples, however.

The sample capsules were irradiated in a flux that was found from cobalt monitors to be uniform from sample to sample. After the capsules were cut open, the pellets were photographed in the hot cell at Chalk River.

Incipient melting was observed at $\int_{\text{pellet surface}}^{\text{melting point}} kd\,\theta$ of 18.5 watts/cm in the case of stoichiometric UO_2 while melting at 72 watts/cm was determined on the 4-m/o-Y_2O_3-doped sample from the diameter of the melted zone. Measurements carried out at Sylcor in a tungsten resistance furnace showed a melting point of 2,698° for UO_2 and a solidus temperature of 2,734° for 4-mo-Y_2O_3-doped UO_2.

From this information, it was established that the average thermal conductivity of stoichiometric UO_2 from 250° C to its melting point is 10% greater than for UO_2 containing 4 m/o Y_2O_3. In spite of the possibility that the presence of more voids in the sample containing Y_2O_3 additive would tend to lower thermal conductivity, perhaps up to 10% relative to UO_2, these results on a typical low-valent addition indicate that a real improvement of UO_2 thermal conductivity by the introduction of additional carriers appears unlikely, unless some means is found for introducing an effective room-temperature carrier content approaching 10^{21} holes/cm^3.

Detailed results of these studies will be published in a Sylcor report.

—R. M. POWERS, Manager
Chemistry and Ceramics
Sylvania-Corning Nuclear Corp.
Bayside, New York

Reactor Antibiotics

DEAR SIR:

In the summer of 1959, a growth of bacteria appeared in one of the auxiliary light-water cooling circuits of the Chalk River NRU heavy water reactor. A comparison of this growth with the bacterial "infection" of the Omega West reactor (E. B. Fowler *et al.*, NU, April, 1960, p. 102) shows some interesting differences.

The bacterium in NRU—also of the genus *Pseudomonas*—was first noticed when stringy growths appeared within the rotameters in the water circuit that cools rods in the reflector region of the reactor. This is a closed circuit normally filled with deionized light water.

When cultured on nutrient agar, the organisms grew rapidly at both 75° F and 95° F under aerobic conditions,

producing white, raised, sticky colonies. There was little growth in deep stab cultures (anaerobic). In liquid nutrient broth, a stringy surface growth appeared.

Because the sticky strands of bacteria might interfere with the operation of the rotameters, it was decided to clean up the system as soon as possible—if a noncorrosive bactericide could be found.

Sixteen compounds that might have met with approval from the Corrosion Group were tested at various concentrations in nutrient broth and cooling water. The compounds included antibiotics, phenols, phenates and dyes. Of these, only three (oxytetracycline, sodium hypochlorite and sodium dichromate) prevented growth of the *Pseudomonas* in concentrations of 100 ppm or less.

The Corrosion Group approved the use of sodium dichromate (120 ppm) in the system. Treatment was carried out during a scheduled reactor shutdown in October, 1959.

A concentrated dichromate solution was injected until the required concentration was reached. The solution was then circulated for 72 hr with the ion-exchange column closed off. The ion-exchange column was then valved in and the solution was circulated for a further 72 hr. Distilled water was used to flush out and refill the system, and the ion-exchange resin was replaced.

No further growth of bacteria has been observed in the circuit since treatment.

—I. L. OPHEL
Environmental Research Branch
Atomic Energy of Canada Ltd.
Chalk River, Ontario

[EDITOR'S NOTE: For interesting related discussions, see: J. J. Katz, The biology of heavy water, *Scientific American* **203,** No. 1, 106 (1960); J. J. Katz *et al.*, The biology of deuterium, in proceedings of Second United Nations International Conference on the Peaceful Uses of Atomic Energy, vol. 25, p. 173 (United Nations, Geneva, 1958); E. L. Bennett *et al.*, Effect of deuterium oxide on biological systems, *ibid.*, p. 199.

NUCLEONICS would be glad to hear of experience with biological growths in D_2O in reactor or other radiation environments.]

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Many college teachers are faced with this kind of decision year after year. In fact, many of them are virtually bombarded with tempting offers from business and industry. And each year many of them, dedicated but discouraged, leave the campus for jobs that pay fair, competitive salaries.

Can you blame them?

These men are not opportunists. Most of them would do anything in their power to continue to teach. But with families to feed and clothe and educate, they just can't make a go of it. They are virtually *forced* into better paying fields.

In the face of this growing teacher shortage, college applications are expected to *double* within ten years.

At the rate we are going, we will soon have a very real crisis on our hands.

We *must* reverse this disastrous trend. You can help. Support the college of your choice today. Help it to expand its facilities and to pay teachers the salaries they deserve. Our whole future as a nation may depend on it.

It's important for you to know more about what the impending college crisis means to you. Write for a free booklet to: HIGHER EDUCATION, Box 36, Times Square Station, New York 36, N.Y.

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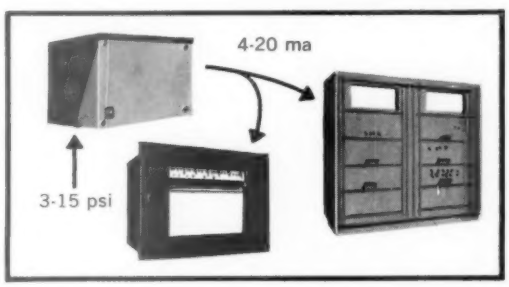
. . . now you can mix electric and pneumatic components

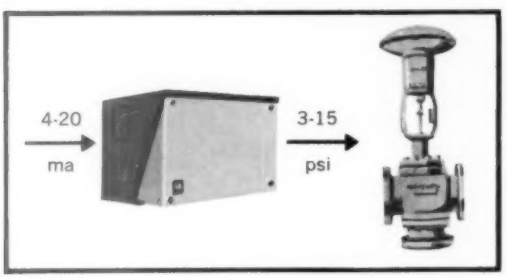
The introduction of Honeywell's complete line of *ElectriK Tel-O-Set* instruments makes electric and pneumatic components completely compatible.

Now you can add the advantages of electric instrumentation to your present *pneumatic* systems. Or, if you are designing a new system, you can use your favorite pneumatic components in an otherwise completely electric system.

Here's an example: You have a pneumatic system but want to record a key variable on an *ElectroniK* strip chart recorder. The answer is an *ElectriK Tel-O-Set* pressure-to-current (P/I) transducer which converts the standard 3-15 psi signal to a standard 4-20 ma signal which can be fed to a data logger or computer as well as to a potentiometer.

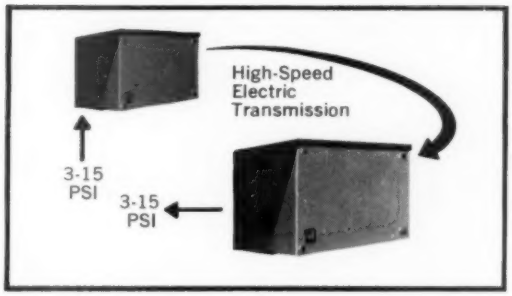


Now let's assume that you are putting in an all-electric system but prefer pneumatic control valve operators. Here the answer is an easily installed *ElectriK Tel-O-Set* current-to-pressure (I/P) valve operator which converts the standard 4-20 ma signal to a standard 3-15 psi signal.



Used separately, *ElectriK Tel-O-Set* transducers allow you to easily intermix electric and pneumatic components. Used together, in pneumatic loops, they give you long distance high-speed transmission and eliminate the lags inherent in long runs of pneumatic tubing.

75th YEAR PIONEERING THE FUTURE



These twins have a calibrated accuracy of $\pm \frac{1}{4}\%$ of span. They're completely transistorized for long, reliable service. Only two wires, forming a series circuit between the two transducers, are needed to carry the signal as well as the system's power. Line power is not required in the field.

Transducers are just part of the story. *ElectriK Tel-O-Set* transmitters are available to convert temperature, pressure, differential pressure, and other process variables into a current signal. To complete your system, you have a wide choice of different types of electric control . . . readouts including meters, indicators, and large case recorders . . . and final control elements.

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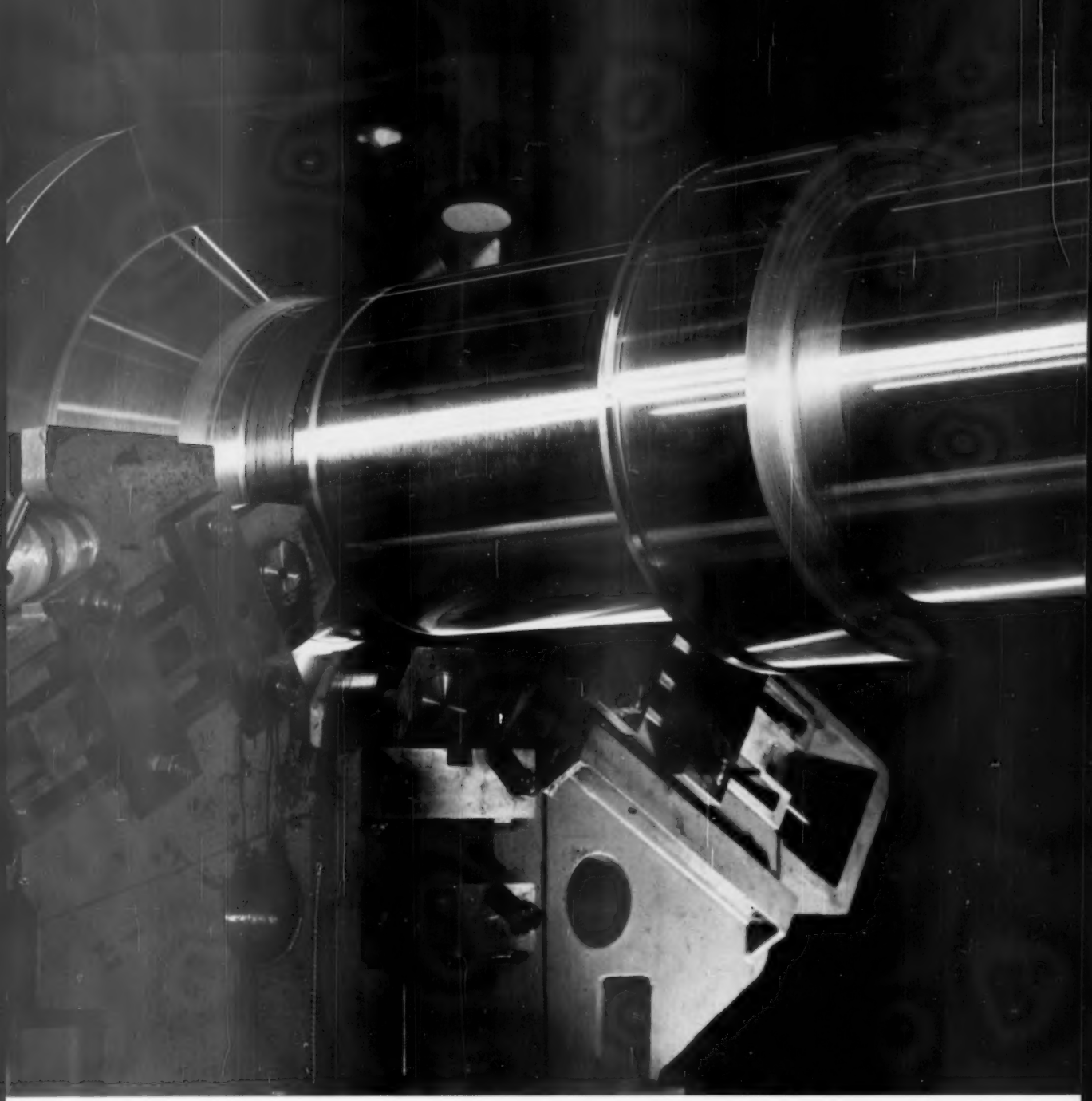
The forging was made from carbon steel cast into a 130″ diameter ingot, smooth forged, heat treated, and rough machined as you see it here. The forging was tested and inspected throughout its processing. As shipped,



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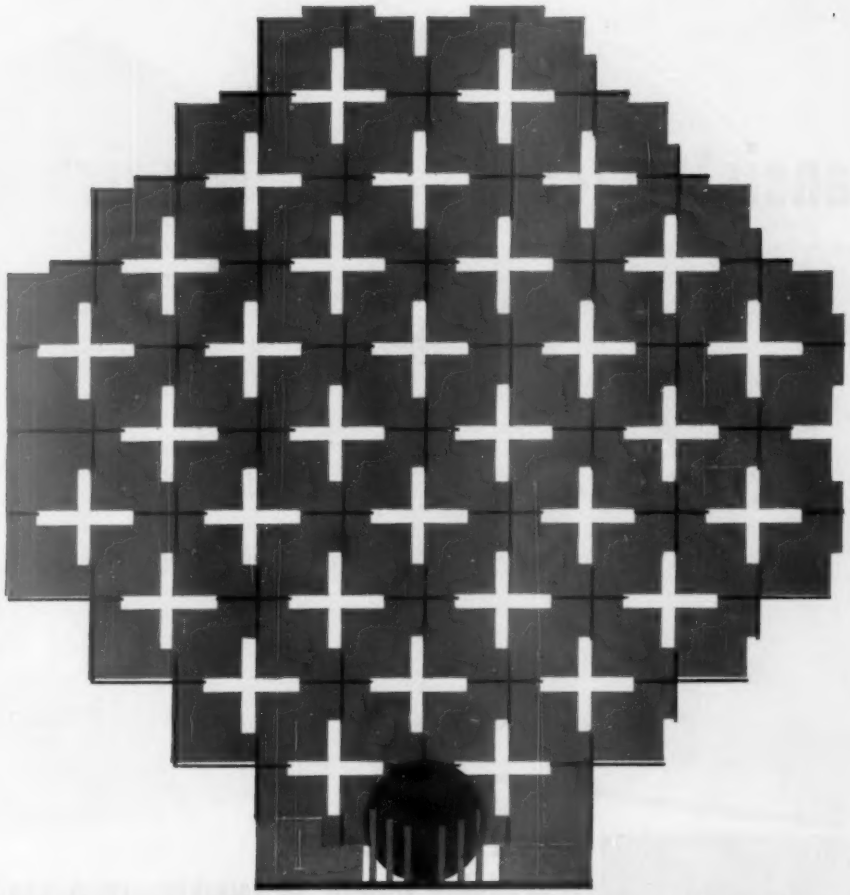

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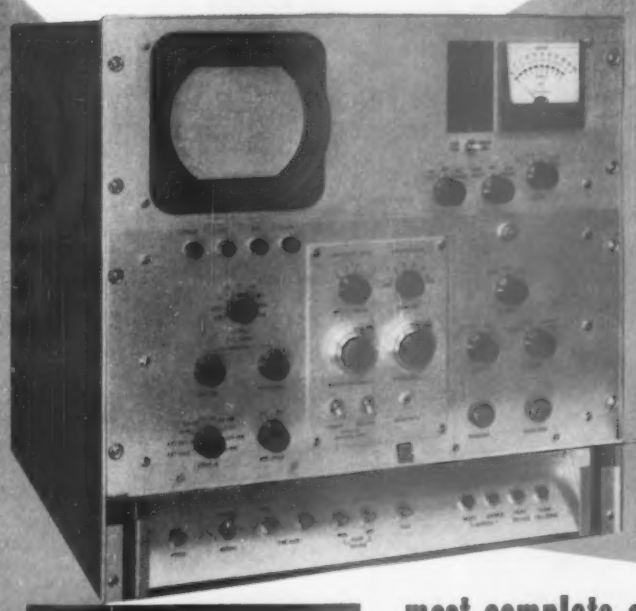

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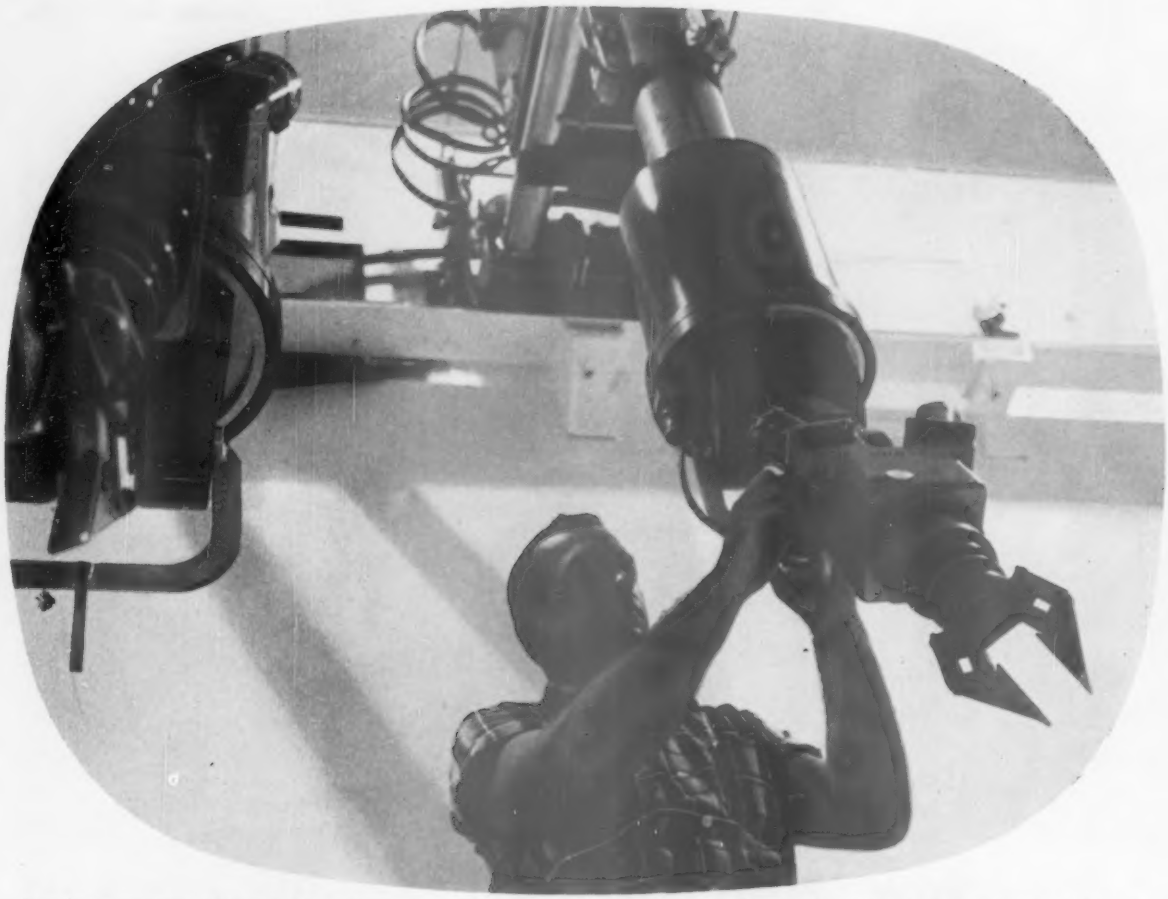

Installation completed, engineer makes final adjustment on General Mills Mechanical Arm.

Photo courtesy of Atomics International, a division of North American Aviation, Inc., Canoga Park, California.

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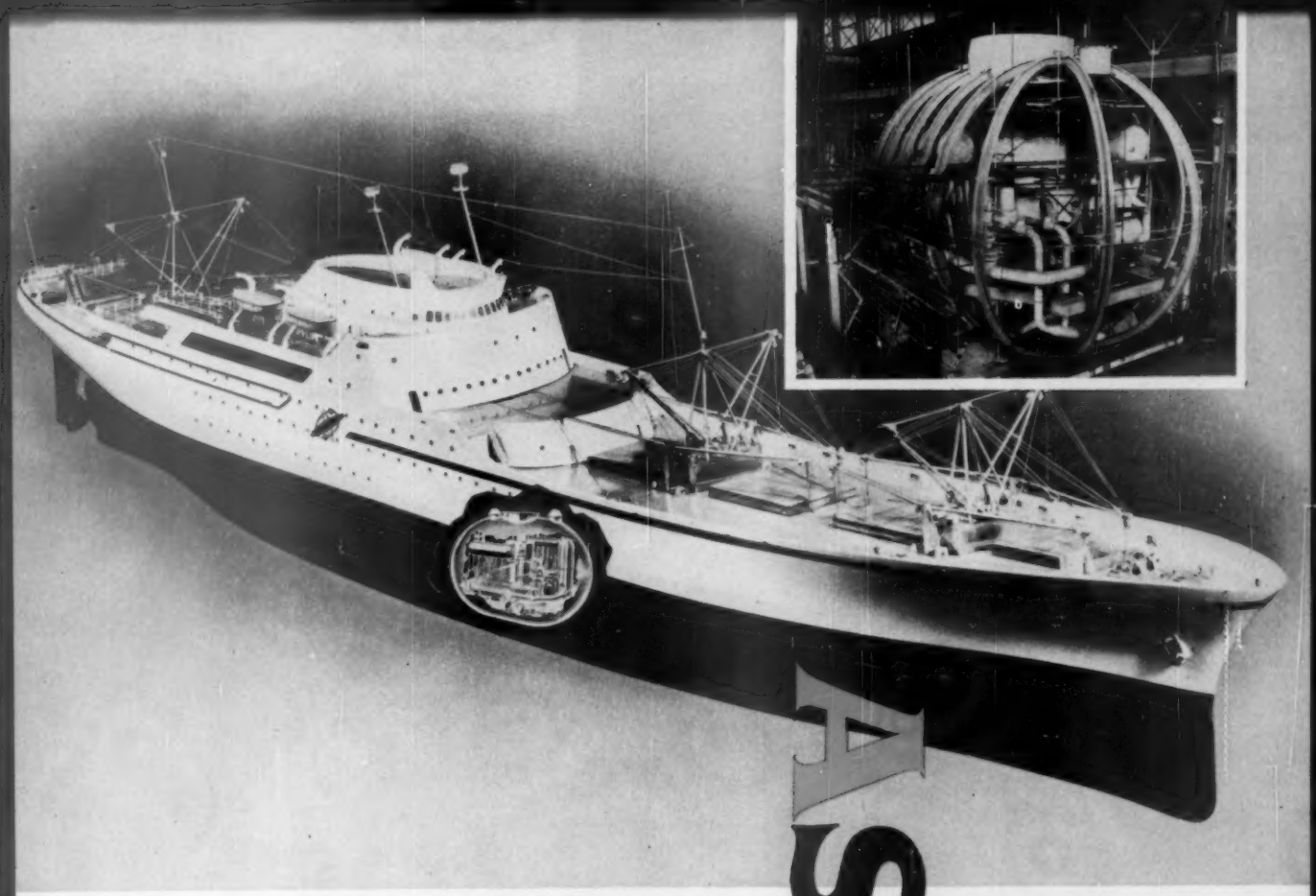

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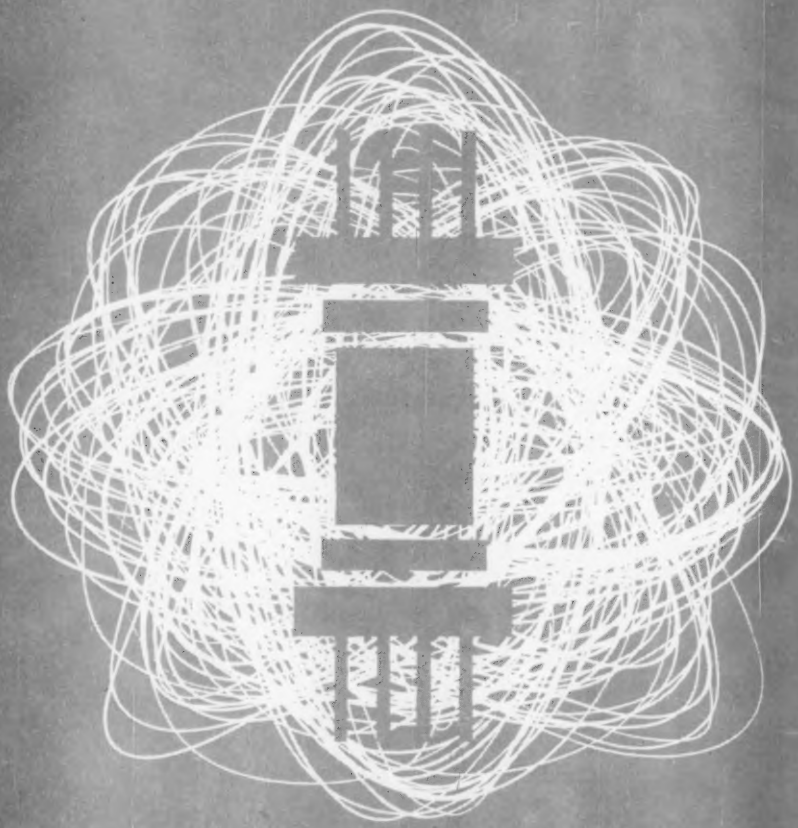

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NUCLEONICS NEWS OF THE MONTH

AEC Tightens Reactor-Change Procedure; Industry Up in Arms

Industrial reactor operators are up in arms about a new requirement AEC is introducing that all changes or modifications in reactor design or operation—not alone those heretofore considered major—be made subject to prior approval from the Commission, in writing.

Qualified observers say the new principle might, in one year, set a company's program back several months—not to speak of direct costs in document preparation, legal talent, etc.

The new principle was laid down by the four-man Commission contrary to the recommendation of the AEC staff. It is being applied first to General Electric's Vallecitos Boiling Water Reactor and to the Westinghouse Test Reactor; but, to be consistent, AEC presumably intends to apply it to all reactors. Both GE and Westinghouse are appealing.

The sequence of events in the matter began with a hearing in April and May this year before AEC Hearing Examiner Samuel W. Jensch on the VBWR. Prior to the hearing, VBWR's license had set up two types of changes or modifications: 1. On those involving changes or modifications to "the design or performance specifications or operating limits or procedures described in this license or the final hazards summary report," written authorization from AEC was required, involving amendment of the license. 2. On other changes to "the facility's design, core design, or performance specifications or operating limits or procedures," GE could make them without prior reference to AEC if it could make certain defined determinations regarding absence of increased hazard—otherwise it had to file a report in advance with AEC on the proposed change; if it didn't hear in 15 days, it could assume AEC approval.

Jensch, in his intermediate decision on VBWR June 12, eliminated CE's right of self-regulation on "minor" changes and made advance reporting to AEC required in every case, although still subject, for minor changes, to the 15-day procedure assuming tacit approval. GE appealed the ruling, and was supported in the principal points of its brief by the AEC staff.

The Commission Rules

The matter then went to the Commission itself. That body, in a unanimous decision Aug. 18 by Commissioners Olson, Wilson and Graham, with Chairman McCone absent, decided to eliminate the 15-day rule altogether and to require approval of the Director of AEC's Division of Licensing and Regulation, Harold L. Price, in every case.

It is understood that the Commission's motive in so doing was to relax, rather than to tighten the Jensch rule—that the Commission sought to eliminate 15 days of certain delay and substitute "informal" approval, i.e., oral, telephonic or telegraphic. But the Commission order contained the phrase that changes "would be approved and made a part of the record"—a phrase that effectively rules out oral or telephonic communications, although covering telegrams or teletypes. Industry feels strongly that whatever the new rule's intentions, it is certain to breed increased delay, not to cut it.

Implementing the Commission's order with respect to the VBWR license, a notice in the Federal Register of Sept. 10 says no change may be made with respect to any matters not specifically covered in the paragraph on "major" changes without written authorization of the Director of the Division of Licensing and Regulation.

Westinghouse, Too

In the meantime, Westinghouse Test Reactor officials have received notification from AEC that their facility would also be made subject to the new procedure unless Westinghouse objected in 30 days. Westinghouse is filing objections; GE has already asked for oral argument before the four-man Commission.

Commented one industry official, "As the rules are now written, we couldn't change a valve in the heating plant or a tile on the floor without approval. We'd have to send a station wagon to Washington twice a day with change requests." This from an operating-level man. Said a policy-level man, "It might be perfectly satisfactory—it depends on how it's administered. It's clear that if it's interpreted so that not only changes of substances, but all changes, have to be cleared—so that we have to report once a day or even once a week—we have a serious problem. But I believe that when it shakes down it might not be so bad."

Oak Ridge planning fused-salt reactor experiment

A 5-10-Mwth fused-salt reactor experiment is planned for construction at Oak Ridge National Laboratory, scheduled for operation in 1963. The plan is subject to AEC appoval but design work is going ahead, pending such approval. Design characteristics include: primary and secondary fluoride salt systems, with a mixture of uranium, thorium, beryllium, zirconium and lithium in the primary and the same mixture without fuel materials in the secondary; primary system temperature of 1,200° F, secondary of 1,100°, and steam of 1,000–1,050°; thermal efficiency of 40%; and extensive use of INOR-8, a nickel-chromium-molybdenum alloy developed by ORNL and several private firms. High hopes are held for savings in fuel costs.

ESUPRA nearing decision on power reactor

The seven-utility ESUPRA group of New York State (NU, Feb. '60, 27) neared a decision last month on whether to order a power reactor of 300-Mwe-plus. The group was completing study of five industry proposals: Atomics International (sodium-graphite), Babcock & Wilcox (spectrum shift), General Atomic (gas-cooled), General Electric (saturated steam and/or nuclear superheat) and Westinghouse (pressurized water).

GE, AIF, Chamber Lead Mounting Public-relations Activity

The mounting concern of the nuclear industry toward a generally negative public attitude on atomic energy has spurred the industry to concrete action. In a series of developments last month intended to bring public recognition of the atom's benefits and the nuclear industry's fine safety record:

1. General Electric announced it had had a national survey conducted to indicate the direction and depth of public nuclear opinion and, as a result of the survey (plus a series of recent incidents indicating a public-relations problem) was preparing a 16-page brochure for dissemination by itself and others in the industry. Simultaneously, GE proposed modification of the "Live Better Electrically" symbol to make it a nuclear symbol—by adding "Citizen Atom," the theme of the new brochure, and two symbols suggesting the atom's value in peaceful and military fields.

2. The Atomic Industrial Forum disclosed that it was considering, in cooperation with AEC and the U. S. Information Agency, the filming of a 28-min color movie giving a straightforward report on radiation and nuclear energy. Still in a preliminary stage, the film would be funded about equally by each of the three sponsors, but AIF would direct its filming.

3. The Forum also said it was participating in the "Citizen Atom" campaign by, first, giving its endorsement and, secondly, by inviting all forum members to order reprints of the brochure. GE has scheduled publication of the pamphlet as a Sunday supplement in the New York Times Dec. 11—a circulation of about 1.5-million copies. GE hopes that at least 3.5-million more copies will be circulated by itself, by utilities and by other manufacturers and others in the industry. The brochure (*see foto*) has been designed to carry GE's name only on the covers, so it can be easily made available without the GE name for distribution by others. Cost of reprints from the Times (available in late November) is $24 per 1,000 copies.

4. A new task force of the nuclear committee, U. S. Chamber of Commerce, was formed to develop public-opinion projects—the "Task Force on Public Understanding of Atomic Energy," which held its organizational meeting Aug. 29 under Chairman S. N. Fiala, vice president and chief engineer of American Electric Power Co.

The Industry's Purpose

In a letter to the task force members, the Chamber's nuclear-committee chairman, Edgar Lee Dessen, defined the force's purpose (and, unintentionally, the purpose of the other efforts now being mounted by GE, AIF, and others): "It is our belief that the public is in need of more factual information concerning the benefits of atomic energy applications and the safety-record of industry in this field. As you know, there has been a great deal of misinformation about the hazards of atomic energy that threatens industrial applications. It is our hope that this task force will review available material on this subject and suggest what else should be done to help in attaining a better public understanding of atomic energy."

CITIZEN ATOM: To run first as insert in New York Times, GE hopes for dissemination by entire industry

As Dessen implies in his letter, the industry is not out to "white-wash" nuclear activities nor to convince the public that there is nothing to worry about. Rather, the intent appears to be to demonstrate that nuclear activities can be conducted with safety (by reporting on the industry safety record) and that the benefits of this technology outweigh the risks (by reporting on the uses of nuclear energy).

More and more nuclear industrialists are expressing misgivings about the public reaction to nuclear incidents, particularly the possible effects on regulation of the industry should a widespread negative attitude take hold. Many feel the problem of over-conservative regulation already exists for the industry (*see page 21*) and could easily worsen unless there is a formal, well-funded, several-sided campaign to inform the public of the positive, as well as negative, aspects of the atom.

GE's Nationwide Survey

The GE survey—the first in five years nationwide—was conducted after the idea took hold within the company that the industry's progress was "no longer solely dependent upon the technical competence and legislative success of a knowledgeable few, but depends upon the understanding, acceptance and confidence of an, as yet, unknowledgeable public."

GE commissioned a Philadelphia survey firm to contact 1,500 households by phone and ask a series of 18 questions. This was done on May 9–19, the interviews running as long as 30 min with men and women in 285 counties and two independent cities. Completed interviews totalled 1,300, which purportedly projects to 129,000,000 persons twelve years or older, or more than 75% of the adult population. Over-all, the survey indicated that a large segment of the population has an entirely negative attitude toward atomic energy and another large segment has no feeling for it at all. Only 23% expressed a purely positive attitude.

"What does atomic energy mean to you?", was probably the most important question asked. The 25% negative response included such comments as: "It is a terrible thing"; "I am scared to death of it"; "Trouble with a capital 'T.'" The 23% positive response included: "Progress in capital letters"; "Something that will open up an entire new future for the world in a good direction"; "An abundant source of electric power." Another 13% reacted both ways "Man's best friend and man's worst enemy") and 26% had no reaction.

A series of six questions on military and peaceful uses of atomic energy indicated that: **1.** there is overwhelming support for nuclear weapons in the defense arsenal; **2.** more than half the population feels that working in a nuclear plant is not as safe as working elsewhere; **3.** half the population feels nuclear power will mean cheaper electricity; **4.** that 70% feels that stocks of nuclear companies are good investments (an interesting positive reaction); **5.** that, as with the military atom, there is an overwhelming desire (84%) to see the U. S. develop peaceful uses of atomic energy for "world-wide prestige"; and **6.** that 62% of those interviewed agree that atomic power should be used to produce electricity (only 6% disagreeing but 32% having no opinion).

Some '60 AEC Reactors Still Stalled; Los Angeles Set Back

The projects comprising AEC's 1960 reactor program, which had been proceeding slowly enough already—with several of them stalled—last month saw one of them unexpectedly shift into reverse and move a step backward. In a most unusual, perhaps unprecedented step, AEC on July 21 recalled the draft contract with General Electric it had submitted to the Joint Committee June 21 for its approval of the terms under which GE would build the 50–75-Mwe Improved Cycle Boiling Water Reactor at Saugus, Calif, for operation by Los Angeles Dept. of Water & Power and Pasadena Municipal Light & Power Dept.

The recall came just in time to head off an investigation by Rep. Chet Holifield, next year's chairman-presumptive of JCAE, whose constituency falls within LADWP's system area. It started after two of the three disappointed also-ran bidders—Allis-Chalmers and Combustion Engineering (Westinghouse was the third)—had called attention to certain "arithmetical errors" in the proposed contract. The errors were understood to involve transposition of two digits in a figure for fuel cost in (or close to) the final-column summaries, where addition of the column resulted in propagation of the error and its introduction into the final cost figures. The recall left a slight shadow of doubt whether GE would build the reactor, although Washington observers felt it was unlikely that another manufacturer would carry off the prize.

Allis-Chalmers, in a letter it wrote to the Commission (a letter later circularized to members of JCAE) said it had offered to build the ICBWR for $1-million less than the announced contract prize to GE. (Total price of the reactor to AEC had previously been given as $12.5-million including the first core and some spares, with the two utilities each contributing another $5-million toward the turbogenerator set.)

It was pointed out, however, that AEC had made its selection not solely on the basis of price but also on contribution to advancing the art; features of the GE design such as internal steam separation were reported to have weighed heavily in its selection.

The matter was still under "re-review" by the Commission as this issue went to press.

Meanwhile, the General Accounting Office reported informally to JCAE on the situation after "taking a look lightly" at the selection process. Such a look does not constitute an investigation.

At least tacit approval (through the lying-before-JCAE-30-days device) of Congress is required before anything could be done to begin plant construction, and with Congress now out of session this would delay commencement of work until the new Congress convenes next year. However, it is generally felt that JCAE would grant waiver of the 30-day rule once AEC has completed its study of the contract situation.

Other Projects

SSPWR. The 16.5-Mwe Small-Size Pressurized Water Reactor has been stalled awaiting a decision on which public utility—the municipal power department of Jamestown, N. Y., or Dairyland Power Cooperative of La-Crosse, Wis.—will get the nod from AEC to have the reactor built on its site, provide a turbogenerator set, and operate the whole plant. Jamestown's proposal is preferred by AEC because the city, being in a higher-cost-power area, made a better offer on the price it will pay AEC, the reactor owner, for steam. But its site has twice been informally turned down by the Advisory Committee on Reactor Safeguards. Dairyland's site, on the other hand, has gotten an informal green light by ACRS.

AEC may ask Jamestown to try to find another site outside the city, further from the built-up areas (but this is understood to involve problems of land annexation, taxes, etc.); it may approach Dairyland for more favorable terms; or it may negotiate with both simultaneously.

American-Standard or Alco Products is believed to be AEC's choice to build the reactor. They were among five bidders on SSPWR, with Allis-Chalmers, Martin, and Westinghouse.

Construction start on SSPWR has now fallen six months behind the original May 1960 date listed in initial schedules.

ELPHR. The Experimental Low-temperature Process Heat Reactor, driven out of its prospective site at Pt. Loma, Calif., by ACRS and Navy opposition (NU, April '60, 30; map, NU Wk, 24 March '60, 1), is still homeless. AEC is now studying several Commission sites, to determine which could make best use of the process steam. AEC's partnership with Interior Dept. to use desalinization of water as the first demonstration task for nuclear process steam has now evaporated. AEC's ELPHR will be put to some other process use, and its size may be changed. A high AEC official said there is a "very good chance" the project will go forward. It requires approval by the four-man Commission.

IOR. The Intermediate Organic moderated and cooled Reactor, a 50–75-Mwe unit in which public utilities had failed to show any interest on AEC's first invitation, is now planned for construction by AEC. A recommendation that it be built has gone from the staff to the four-man Commission. A yes-or-no decision is expected by Jan. 1. Advances in research-development on a proposed core using sintered aluminum powder cladding is expected to favor an affirmative decision. Meanwhile AEC is shopping for an architect-engineer, and would still like to hear from any interested public utility.

EOCR. The Experimental Organic Cooled Reactor, a 20–40-Mwth non-power-generating facility for experimentation to develop economic organic power reactors, is moving ahead smoothly on design work and a construction start in early spring is planned.

VBWR, SRE go critical again

After long shut-down periods, Vallecitos Boiling Water Reactor and Sodium Reactor Experiment came back to criticality. VBWR underwent a 10-month, $1-million modification: a new core structure, new circulating water pumps. SRE, following core repairs and replacement of 16 graphite moderators cans necessitated by the July, 1959, accident (NU, Dec. '59, 23), went critical on its second core. This thorium-uranium loading, using five-rod metallic clusters containing 7.6% by weight U in Th, as against the first core's seven-rod clusters of pure U metal.

Nuclear propulsion for B-70 bomber studied

North American Aviation (Atomics International's parent firm) has completed a 6-month, $200,000 Air Force feasibility study on nuclear propulsion in the planned B-70 bomber.

Purdue Team Produces Controversial Report on Legislation

A preliminary but provocative report on atomic energy legislation and on the overall nuclear effort in the U. S. was completed five months ago for President Frederick L. Hovde of Purdue Univ. and the Atomic Industrial Forum. Despite an extremely limited circulation (only Forum directors have seen it officially), the 51-page report has become a controversial industry document of a "sweep-it-under-the-rug" nature and has prompted outspoken misgivings among some industry leaders toward Purdue's plans to follow it with a more comprehensive study.

Authors of the report were Ralph K. Davidson, an assistant dean of Purdue's Graduate School, and Walter H. Warrick, a graduate student in the School of Industrial Management. They prepared it early this spring and presented it to Hovde after four months of work—interviews with industry and government officials and reading of pertinent documents. Hovde had agreed to ask his people to make the effort at the request of the Forum (NU, Aug. '59, 20).

Since, as the report's foreword stresses, it is a "preliminary report" which "is intended as a point of departure for a full scale review of atomic legislation," Purdue is in the process of seeking a Ford Foundation grant to support a full-blown study. This would take an estimated 12–30 months, depending on the numbers of people assigned to it, and would involve the use of legal, nuclear-engineering and other consultants off the Purdue campus.

INDUSTRY REACTION MIXED

The majority industry reaction to the preliminary effort was summed up by an industry official last month: "The report is a rather naive, unsophisticated approach to a complicated problem [nuclear legislation] by people who are not close to the industry." However, there are some industry leaders who have welcomed the report for chiefly two reasons: 1. it was an academic, honest attempt to reflect the opinions of industry executives; and 2. it raises basic questions about the nuclear program which industry should not ignore. A sympathetic industry leader commented:

"Sure there is criticism [of the report]. But, in my opinion, this is the kind of criticism you get when you get up in the morning and look at yourself in the mirror and say: 'Who is this horrible creature?'. When you get this kind of mirror [from talking to industry executives], you know very well something needs to be done. . . . This emphasizes the shallowness of the thinking going on and the need for some deep thinking."

Purdue was asked to conduct the study, it was pointed out, because an analysis of the 1954 Atomic Energy Act and the effects of its provisions, "has to be done by some non-committed organization." If such an effort were sponsored or financed by the Forum, it was emphasized, its effectiveness would be impaired. The Forum recognizes, this official said, "that it can't control the study or sponsor it."

PURDUE'S Hovde and study team Davidson, Warrick

An Academic Look at Nuclear Energy

Running through the Purdue report, particularly in the two sections preceding specific suggestions for areas of legislative study, are several particularly pointed comments on the nuclear program:

"Taking a general view of the 'race' [for international leadership] as it looks today, it appears to be one in which all the contestants are walking."

"The apparent loss of momentum of the atomic energy program suggests an examination of the extent to which the [1954] Act was successful in promoting an 'atomic industry' in the U. S."

"When, with the enactment of the [1954] Act, the government began to encourage the private sector to take part in the development of atomic power . . . . it seems apparent that there was widespread overoptimism as to the investment in time and resources which would be necessary to reach the goal of economically competitive power, and the willingness of the private sector to make the investment."

"Since additional government support for the development of the peaceable atom will be at the expense of other, potentially worthwhile projects, a careful analysis deserves to be made before responding to industry's request for additional government incentives. Five years of experience and expense and the literal appearance of a new star in the firmament [the space program] have dulled the glamor of the atom and permit the realistic appraisal which was not possible amid the hopes and fears of 1953–54."

THE REPORT'S SUBSTANCE

Davidson and Warrick used some strong language in appraising the U. S. nuclear program and summarizing their findings. "After five years of experience [under the 1954 Act]," they said, "no part of the reactor fabrication and supply industry has reached the point of profitable operation and only one sizeable reactor wholly financed by private industry has been completed. Furthermore, at the present time it seems generally agreed that no sudden breakthrough into the achievement of a readily portable, inexhaustible, inexpensive power source is likely. Atomic power technology has not developed with the rapidity hopefully anticipated by many in the period 1953–54.

"In the U. S., at current prices, plentiful supplies of fossil fuels exist, thus eliminating economic pressure for a strong federal effort to promote early, large-scale domestic expansion of nuclear power utilization. On the other hand, the development of economically competitive electric power from a nuclear source may have sufficient international political impact to provide a case for such an effort. If this is so, the benefits gained from government expenditure on atomic power development must be weighed against the advantages to be derived from expenditure of government effort upon such projects as the space race, which are also justified on the basis of national prestige and potential scientific gain."

Turning from this allusion to the space program as a new competitor with nuclear energy for government dollars, Davidson and Warrick concluded that competitive nuclear power could be attained most efficiently by assigning clearly to government and industry their respective research-and-development roles.

"The governmental role is best adapted," they pointed out, "to activities resulting in no immediate payout and

those involving long or wide ranging responsibilities to the nation. In the atomic field, this would involve such things as broad guage or basic research, waste disposal and public health and safety. On the other hand, the special talents of private enterprise seem generally to be in applied research and in reducing the costs of fabrication and utilization.

"It is upon the basis of optimizing the division of effort between government and the atomic industry that a detailed reexamination of the law is suggested."

OTHER RECOMMENDATIONS

The Purdue team made these other recommendations on areas of nuclear legislation that might or might not require further, more detailed examination beyond their preliminary study:

1. Patents. While many believe the departure from normal patent procedure has inhibited entry of firms into the business, experience under the law "indicates the development of a patent policy which the industry can 'live with.'" At least for domestic patenting, "it does not seem that a reexamination of . . . policy would be useful at this time." For foreign patent policy, where industry has several complaints, "further investigation of the . . . situation is indicated."

2. Information. An excess of red tape exists in some areas and "a systematic examination of the information service practices of AEC might suggest positive techniques for organization and dissemination of pertinent information to groups who could make the most use of it." The team was not specific on red tape.

3. Subsidy. ". . . a possible revision of the subsidy provisions of the 1954 Act to permit further aid [to industry] should have a high priority in a study undertaken at this time." The report said a capital subsidy to both reactor manufacturer and utility would recognize the special interests of each in a given project; it would also be a recognition, the report suggested, that the various forms of government aid to date have not only had "practical difficulties" but also led to "apparent competition between the government and industry." Any capital subsidy should offer "fractional rather than complete coverage of the differential between a conventional and a nuclear plant in order to mimimize the bias in favor of a high capital cost plant."

Regulation. "The knottiest potential hindrance to atomic progress is provided by the health and safety regulations." While the public safety should be uppermost there are suggestions that some regulations "are either overly cumbersome or impracticable. . . . A detailed examination of the safety and licensing regulations of AEC should provide some useful suggestions for altering the pattern of regulation if not the substance of the . . . Act."

Anti-monopoly. "The specific anti-monopoly provisions of the Act . . . seem in themselves to have provided no serious impediment to industrial development of atomic energy. . . . Here, as in the case of the [domestic] patent provisions, seems to be a place to let sleeping dogs lie."

New Canadian Association Founded to Represent Industry

To stimulate Canada's growing nuclear industry, to keep members of that industry currently informed of developments, to coordinate the common interests of all organizations and individuals interested in Canadian nuclear progress, the Canadian Nuclear Association was founded last month.

Spokesmen said the objectives of CNA are broadly similar to those of the Atomic Industrial Forum, though applied specifically to Canadian conditions. However, they indicated that CNA might differ significantly from AIF in one respect, in that it's hoped it would take positions and vigorously uphold its point of view—eschewing AIF's nonpartisan, above-the-smoke-of-battle approach. CNA will also "seek the establishment of a public attitude" supporting "continuous and planned increase" in construction of nuclear power plants.

A steering committee, the list of whose members reads like an honor roll of Canadian nuclear industrialists, had been working to set CNA on its feet since the first Canadian conference on uranium and atomic energy held in Toronto in January (NU, June '60, 27). Its efforts bore fruit at a Toronto meeting Sept. 7, when the steering committee became an advisory committee, and a new board of directors was named with Ian F. McRae, chairman of the Board of Canadian General Electric, as president; and Hon. Robert Macaulay, Ontario Minister of Energy Resources and vice chairman of Ontario Hydro,

CANADA'S MacRae, Macaulay, elected to top Association posts

as vice president. A search is on for a full-time general manager.

Membership Drive

A preliminary survey of interest in membership showed 163 favorable replies from industrial and governmental organizations plus another 21 from universities. More than 400 firms are serving as suppliers to Canada's first power reactor, the 20-Mwe Nuclear Power Demonstration Reactor (NPD), and a membership drive to reach this broad base for potential members is to be launched shortly. Moreover the base itself is expected to grow: CNA points out the $80-million Douglas Point reactor (200 Mwe) is to be started this year, and predicts expenditure of more than $120-million on nuclear power development in the next five years.

CNA's aims were set out by the early September meeting of the board of directors as follows:

"1. Promote and foster an environment favorable to the healthy growth of the uses of nuclear energy and radioisotopes.

"2. Encourage cooperation between the various industries, utilities, educational institutions, government departments and agencies, and other authoritative bodies that have a common interest in the development of economic nuclear power and uses of radioisotopes.

"3. Provide a forum for the discussion and resolution of problems which are of concern to the members, to the industry or to the Canadian public generally.

"4. Cooperate with other associations that have similar objectives and purposes, particularly the U. S. Atomic Industrial Forum and the European Forum."

To achieve these ends, CNA will assist in analyzing major industry problems, setting up study groups where necessary; publish a journal; offer aid in drafting special regulations affecting member organizations; act as an information center for members; and arrange conferences and meetings, including an annual conference with both technical and nontechnical papers and discussions, etc.

Instrument Industry Maturing, But Speedy Growth Continues

The radiation-instrument industry is going through a maturing process that is manifesting itself in a variety of ways. Whether this is a "revolution" or "evolution" is not certain (and probably academic), but an informal NUCLEONICS survey of instrument executives—primarily in the Chicago area—brought some frank talk of an industry dominated by sheer dynamics and growth. Some survey highlights:

- In a somewhat schizophrenic display, the industry is experiencing a "shakeout" or consolidation, on the one hand, and a continuing formation of new firms, on the other. Increasingly tough competition and narrowing profit margins are forcing and expected to continue to force some companies to diversify into other fields, or to consolidate with other firms, or to get out of the business. At the same time, the founding of new firms—usually by former employees of established firms—has continued, in many cases spurred by the refusal of the established firm to get into new services or instruments.
- There is an increasing emphasis on expenditures for research and development—to design new instruments from the ground up, plus special features and accessories that might provide a competitive edge. Research staffs are growing as the industry gets away almost completely from its former dependence on AEC's national labs for development of new instruments. Conversion from electron tubes to transistors and printed circuits is proceeding, although the rate of conversion is by no means uniform.
- Relatedly, more money is being committed to efforts to develop new instrument concepts and new markets —where no competition exists or where it is minor, particularly in the industrial, non-nuclear field.
- There is a continuing, and apparently accelerating, trend toward public ownership of instrument companies as those who are successful look to the public for funds to expand. In many cases, these firms must expand or stagnate and—either for this reason or for personal-estate reasons—public offerings are scheduled. Expansion of physical plant and development of new instruments and enlarged sales forces are the primary motives for seeking public investment.

Manpower Problems

In addition to these signs of change and growth, there are several others particularly characteristic of this industry, all of which might be lumped under one heading: "manpower problems." There is a need for management people of broad experience and there is a phenomenon which continues to be as much of an irritation to the established firms as it ever was —the loss of good people to other competitors or to their own new firms. The survey brought out these manpower developments:

- Some instrument companies are trying to strengthen themselves by establishing management staffs with expertise in many fields of operation that company founders do not have—finance, manufacturing, sales, etc.
- There is evidence that some companies are trying to crack down on the kind of "musical chairs" game that some top-management and scientific employees are purportedly playing. The reaction to such employee mobility has reached the point where at least one firm, Packard Instrument, is considering contracts for key people which would prohibit their leaving for similar jobs with competitors —or to found their own companies— for a period of two years.
- In the same vein, there is evidence that some firms are going outside the nuclear instrument industry to recruit new talent. This is partly because of the shortage of nuclear people and partly because some feel they can achieve more stability in their staffs by bringing in outside people and training them, than by hiring people with a history of job-jumping. Among other things, this indicates that the industry may become less "inbred" than it is now.

New-instrument Development

All firms contacted said they have been building up their research-and-development staffs and committing an increasingly large share of their budgets to new-instrument development. The concensus appeared to be that as much as 10–20% of sales was now going into new instruments. Much of this attention is going to instruments to be marketed outside the nucleonics field—instruments that have no nuclear connotation whatsoever or instruments for use with radioisotopes, for example, in other industries (process control, etc.).

Several firms looking to the space program for business describe this business as particularly attractive because the program pays for development of new instruments which have much broader market potential (in missile and other industries); the space program itself is not considered a major market by most but the "free" research-development dollars make space contracts worthwhile. Radiation Instrument Development Lab and Tracerlab are two firms developing instrumentation especially for space—RIDL producing a one-watt multi-channel analyzer (less than 3 lb) for the National Aeronautics and Space Administration and Tracerlab working on clathrate, gas-measuring devices for NASA, the Navy and the Air Force.

Baird-Atomic, which estimates its spending for instrument-development "in the neighborhood" of 15% of sales, has also gone to a new West Coast firm for new instruments: Sharp Laboratories, La Jolla, Calif. Sharp recently sold the designs of five instruments to B-A: a laboratory monitor and rate-meter, a precise pulser, a transistorized scaler, a transistorized radiation alarm and a "peak squeaker" for adjusting gamma spectrometers. Baird is also indirectly capitalizing on the new-instrument program of Sharp (primarily low-level counting) by acting as its sales agent world-wide.

Sharp itself is banking on non-nuclear industries to purchase much

Still Alive: Instrument Trade Group within Forum

Leaders of the radiation-instrument industry are engaged in another effort to form a trade-association type of body which might deal with industry-wide problems (NU, May '60, 23). The effort is to create a committee within the Atomic Industrial Forum representing this industry. An initial meeting of industry executives, held in late June, was not successful—the attendees unable to make any progress. Largely because of this unsuccessful meeting and because of major divergencies of opinion on such questions as what problems such a group might deal with, a second meeting which had been scheduled for Aug. 24 was postponed to early fall.

In the meantime, an effort is being made informally to pinpoint specific areas of discussion and to persuade an industry executive to take the lead in organizing a Forum committee—a person around whom the industry would be willing to rally. The major projects which most executives feel a Forum committee might tackle include: 1. the development of sophisticated industry statistics, including market information; and 2. the presentation of industry views on questions like government competition to AEC, Congress, etc.

of its equipment, an attitude which is gaining steadily in the entire industry. Nuclear-Chicago sees its real growth in the use of radiation for process-control and Radiation Counter Laboratories reports an upsurging interest by the steel, chemical and other industries in radiation equipment. RCL has the largest research-development staff in its history—a staff which produced 16 new instruments in the year ended June 30. Nuclear-Chicago has no less than one-third of its roughly 300-man staff working on new products and N-C intends to expand this group at about the same rate as growth of sales.

Packard Instrument is another firm expecting to do more business outside the nucleonics field but not to the point of having this business exceed sales to the nucleonics industry. The firm predicts increasing emphasis on low-level counting, where it feels it has an edge on the competition through its liquid-scintillation program. Increased sensitivity of measurement will offer both cost savings and health-and-safety advantages, the company emphasizes, by lowering the amount of radioisotope required in a particular system.

AEC's National Labs

There is a curious duality of attitude among industry executives toward AEC's national laboratories which, until recent years, have been an incomparable source of both instruments and manpower for the industry. On the one hand, the labs are attacked unmercifully for their procurement policies and for alleged competition with the instrument industry; on the other hand, there is fear among some industry executives that the decline of instrument-development capability at the national labs threatens to weaken the overall instrument capability of the U. S.

The point is made that this rather small industry does not have the research-development wealth required to maintain a world leadership position in radiation instrumentation, and that the industry should speak out for resurrection of the national-lab complex as a meaningful contributor to new-instrument technology.

The criticism of lab procurement policies is particularly widespread and vocal. More than one executive accuses the labs of playing one company against another in letting equipment contracts. It is felt that this is detrimental to the winning, as well as losing bidders, because sales are often made below cost. "The labs apparently feel the vendors shouldn't make any money," observed one official whose firm no longer bids on lab invitations. "Several companies whose business was predominantly with national laboratories have had to go out of business. This is not building a healthy industry."

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Skate sets core-longevity records

The Navy's third A-sub, *Skate*, has completed 36 months on its first core and has steamed 112,000 mi, but has not yet been scheduled for refueling, the Navy said replying to a NUCLEONICS inquiry. *Nautilus*' first two cores, each with ~26 months residence lifetime, took her 69,100 and 93,000 mi; *Seawolf's* first core last 23 months, 71,600 mi.

Transistorization

As might be expected, there are almost as many opinions as knowledgeable people on the speed, extent and significance of the industry's swing to transistorized equipment. Some firms are transistorizing as quickly as possible; others are doing it on a long-range, multi-year schedule and on a highly selective basis. There is agreement by all, however, that virtually all instruments will be transistorized within a few years.

In any case, transistors and printed circuits point to instruments of considerably better performance and, eventually, to nearly "fail-safe" instruments that will rarely cause trouble.

RCL, where all equipment except low-priced scalers and rate-meters have been transistorized, feels there may be too much emphasis on transistorization ("The pendulum is definitely swinging toward transistorization and it may be overswinging."). N-C also looks at transistorization with some restraint ("We use transistors where they do the job better, but there is no crash program to transistorize here."). This firm's transistorization emphasis is given to portable instruments, where the size saving is significant, and to lab instruments where the transistor advantage is clear.

Toward printed circuits, N-C's attitude is a little different—recognizing their advantages in instrument assembly and predicting that N-C will use more and more of them. "There is a limit on getting top quality at *any* cost," an N-C spokesman pointed out. "Anybody can have top quality at any cost. The emphasis must be on achieving top quality at *reasonable* cost."

Going Public

In an era when public issues have been going "like hot cakes," it is little wonder that some of the privately held instrument companies—some in business for many years—are finding it difficult to resist public ownership. However, for most radiation-instrument firms it is quite simply a need for acquiring the wealth to expand. While this could be done via merger with a wealthier firm (and is being done in some cases), the preference is for public stock sale, which provides new money while permitting a higher degree of retained control than does merger with a larger firm.

RIDL plans to "go public"—after ten years of one-family ownership—this fall or winter, expecting to raise $1–1.5-million. The new capital will permit RIDL to both build new facilities and expand into the space, missile and other areas of electronics. This year's sales have been running about $2-million. The goal for fiscal 1961, ending June 30 next year, is $3-million—but this depends to a large extent on how fast the company can expand.

Another long-privately-held firm, Packard Instrument, says there is a "real possibility" it will offer stock to the public next year—again the need for new and larger facilities being a major motive. The firm has experienced an annual doubling of sales in the last three or four years to about $3-million/yr currently. From 1959 to 1960, however, Packard saw the first slowing of this rate, with sales this year expected to be about 50% higher than last.

REACTOR NEWS

YANKEE GOES CRITICAL, ELEGANTLY

On the night of Aug. 19 the nation's second private large-scale power reactor, the 134-Mwe pressurized water unit of Yankee Atomic Electric Co. at Rowe, Mass., went critical. It started driving at once through its low-power testing program on a three-shift basis in an effort to be in commercial utility operation before year's end. Veterans of other reactor startups who watched proceedings in the control room said it was one of the smoothest startups they had ever seen; the approach began at 6:30 pm and criticality was achieved at 8:19. It was calculated to be reached when—after the outer control-rod group (8 of 24 rods) had been withdrawn 40 in. from the 90-in. core—the inner rods were withdrawn 44 in. Actually, the reactor went critical when the inner rods (two groups of 2, three groups of 4 rods) were inched out, 3 in. at a time, to only 36¼ in., indicating either a more reactive core, or slightly greater rod worth, than expected. Yankee's low-power testing program is expected to take ~60 days. It encompasses measurement of temperature, pressure, flow and void coefficients, rod worth, and boron worth (the primary water contains 1,600 ppm boron as boric acid to keep the core 10% subcritical with all control rods and shims in place). As soon as low-power testing is done, Yankee will start going up stepwise to 392 Mwth (= 110 Mwe), for which it already has AEC authorization; after 500 hr operation at that level, Yankee is to report to AEC to seek the full-power license.

PUERTO RICO'S SECOND REACTOR CRITICAL

The 1-Mw pool research reactor built by AMF Atomics for the Puerto Rico Nuclear Center at Mayagüez went critical Aug. 16 (just one year after the island Commonwealth's first reactor, a low-power Atomics International L-77 solution type, started up Aug. 19, 1959, also at Mayagüez). One week later on Aug. 23, Commissioners John Graham and Robert Wilson and Rep. Chet Holifield of JCAE dedicated the pool reactor, then moved 15 mi northwest to Punta Jiguero to break ground for the island's third reactor and first power unit—the 16.3-Mwe BONUS (BOiling NUclear Superheat) reactor.

VBWR CRITICAL AGAIN

After a 10-month shutdown for modifications, the Vallecitos Boiling Water Reactor went critical again. The $1-million changes included a new core structure and new circulating water pumps. The 5-Mwe reactor had previously operated for 26 months, yet radioactivity was not a serious problem during the overhaul work, according to General Electric, VBWR's builder.

MOTHBALLS FOR AFNETR

The Air Force Nuclear Engineering Test Reactor, still under construction at Wright Field, Dayton, Ohio (contract was awarded in October 1956), is to be completed, then "placed on standby status." An allocation of $1.1-million has just been obtained, enough to complete the reactor; low-power operation is scheduled to start in summer 1961, and "reactor check" will be carried out before the unit is put on standby early in 1962. At Air Research & Development Command in Washington it was explained that the future of AFNETR had been greatly affected by phasing out of the 125-A reference system for a nuclear plane, for which much work had been scheduled in AFNETR. The only other two known instances of reactors being mothballed both involved cutbacks in Air Force work: the research reactor Lockheed built for the AF at Dawsonville, Ga., and the unit Curtiss-Wright built at Quehanna, Pa., largely in expectation of doing work on nuclear planes and ramjets. The C-W unit, scheduled for deactivation, got a new lease on life when . . .

QUEHANNA REACTOR IS GIVEN TO PENN STATE

Curtiss-Wright made a gift of its 1-Mw pool, being modified for 4-Mw operation, to Penn State Univ., ~35 mi. away. Penn State already has a 100-kw pool.

NUCLEAR NAVY NEWS

Scamp, the Navy's 21st nuclear submarine to be launched, will go down the ways Oct. 8 at Mare Island Naval Shipyard . . . SSN621, a *Thresher*-class attack sub, was awarded to Ingalls Shipbuilding Co. for construction for a maximum of $23,405,750—the Navy's 43d A-sub ordered. She is one of four voted by Congress this year; the Budget Bureau has not released funds for the other three. Five Polaris-firing A-subs also voted this year have all been assigned (NU, Sept. '60, 25) . . . *Seawolf*, her conversion to a pressurized water reactor completed, passed her builder's trials Aug. 29, and was recommissioned . . . Work on the cruiser *Long Beach* was back in full swing after a 22-week strike at Bethlehem Steel's Quincy, Mass., yard. Testing of the two reactors' primary loops is getting under way.

HRE-2 HOLES PATCHED

The holes in Oak Ridge's Homogeneous Reactor No. 2 have been patched, in a daring remote operation in a 100,000-r atmosphere. The pioneering unit is to go back into operation as a two-region reactor, with direction of flow reversed (to go from top to bottom of core tank) in an effort to eliminate the hot-spots that burned the two holes in the 5/16-in. zircaloy core tank (NU, May '58, 26; Aug. '58, 21; May, '59, 33).

HYDRAZINE PRODUCTION BY REACTOR: AGN

In-pile tests will start this fall on a new Aerojet-General Nucleonics chemonuclear process for making hydrazine, a space-age fuel, from ammonia, under a one-year Air Force contract. AGN, which had run tests a year ago in the Livermore Pool Test Reactor on nitrogen fixation by chemonuclear reactor, is even more enthusiastic about the prospects for chemonuclearly-produced hydrazine. The tests this fall will use a capsule providing agitation for the contents: anhydrous liquid ammonia and a fully-enriched uranium compound in suspension or solution.

CONGRESSMAN CHALLENGES PEACH BOTTOM

Rep. James M. Quigley (D-Pa.), in whose constituency Philadelphia Electric and its 52 utility partners plan to build the Peach Bottom High Temperature Gas-Cooled Reactor, will seek to intervene at the AEC hearings on a construction permit for the project. Quigley opposes AEC's two-step licensing policy (of construction permit and operating license). He says, "The time to resolve the question of any threat to public safety from operation of the reactor at Peach Bottom is now and not after millions of dollars of the taxpayers' money have been spent on building a reactor which AEC may never allow to operate because it could be too great a threat to the highly-populated areas immediately adjacent. . . Sooner or later AEC will have to determine whether or not it is safe to operate: why not sooner—if there is no scientific reason to prevent a determination sooner, before $40-million is spent?"

WORLD NEWS

Second Pu-Separation Plant for France

France will build a second plutonium separation plant at Jobourg, 7 mi west of Cherbourg, to treat irradiated fuel elements from power reactors now under construction or planned for northwestern France. These include the three Electricité de France reactors at Chinon (NU, Aug. '60, 28), and the 100-Mwe EL-4 that the Commissariat à l'Energie Atomique will build in the Monts d'Arrée 30 mi east of Brest. Although CEA has not announced capacity of the plant, a spokesman indicated that it would be somewhat less than that of the chemical separation plant operating at Marcoule since 1958. Construction on the new plant is tentatively scheduled to start early in 1961.

Work to Start on Britain's Second A-Sub

The Admiralty has placed a contract with Vickers-Armstrong Ltd. for Britain's second nuclear submarine. Rolls-Royce will build the reactor for the vessel to British designs. These will be, NUCLEONICS understands, basically similar to the Westinghouse S5W that Rolls-Royce as the Admiralty's agent procured for installation in Britain's first A-sub, *Dreadnought*. The new unit will, however, include "some British refinements." A land-based prototype will be built, probably at Dounreay, for mid-1962 criticality. The second sub, known so far only as SSN02, will be a hunter-killer type with the specific function of hunting other submarines, rather than surface ships as will *Dreadnought*. Its size has not been revealed, but it is expected to be larger than the ~3,000-displacement-ton *Dreadnought*. *Dreadnought* is to be launched by the Queen Oct. 21 this year; SSN02 will likewise probably be launched 18 months after keel-laying.

Design Contract Signed for Orgel

Italy's National Committee for Nuclear Research (CNRN) and AGIP-Nucleare have signed a design contract for the 30-Mwe organic power reactor prototype ORGEL. CNRN is to organize and finance the $10-million project, AGIP-Nucleare design the reactor, and SORIN—nuclear subsidiary of Fiat and Montecatini—build it, perhaps in the Bologna area. Sergio Gallone will head a joint project staff; U. S. information furnished under the U. S.-Italian bilateral to CNRN will be made available to the ORGEL staff.

France Enlarges Aquilon

The Saclay research reactor Aquilon has been enlarged and improved to facilitate lattice studies for the 100-Mwe heavy-water-moderated power reactor EL-4 to be built in Brittany. Reactor vessel diameter has been increased from 78 to 118 in., nearly doubling capacity; core assembly has been changed to permit easier rearrangement of lattice spacing; controls are improved.

South Africa's First U-Plant Ready

South Africa's first uranium processing plant was to go on the line shortly, as this issue went to press. The plant, with a capacity of 100 tons/yr, is being built at the Government Metallurgical Laboratories at Johannesburg. Financed by the Union of South Africa Atomic Energy Board, it will be operated jointly by AEB and the Transvaal and Orange Free State Chamber of Mines. AEB says the plant will enable South Africa to do its own research on uranium processing techniques as well as to refine part of its own output. This, AEB hopes, will place the country in a more favorable position to offer uranium in a competitive world market. Processing of the country's production of uranium oxide is considered important, since purchase contracts with the U. S. and Britain for over 6,200 tons/yr will begin to run out in about 18 months and are unlikely to be renewed. Efforts by Union authorities to have the contracts extended—to cushion the blow to local products—do not appear to have been at all successful.

Halden Critical Again

The world's only heavy-water boiling reactor went critical again Aug. 26 after a seven-month shutdown for modifications preparatory to full-power operation. These included an unusual repair operation on each of the 316 aluminum-clad uranium metal fuel elements in the reactor's first charge, to remove the effects of pitting corrosion that occurred at the lower end of the 1-in. dia rods due to galvanic action in stagnant water during the first six months of zero-power operation at ambient temperature. Repair was accomplished by shrinking an additional cladding can over the lower 10.6 in. of the 7.8-ft long elements, and welding it to the existing cladding above the pitted zone. After checkout runs and measurement of temperature coefficients, now being carried out, power operation will begin.

GE Signs Contract for BWR in Japan

Following its British namesake (but non-affiliate) by eight months, the U. S.' General Electric Co. signed a contract in Japan for construction of a power reactor, Japan's second, at the Tokai Mura center of the Japan Atomic Energy Research Institute. The 12.5-Mwe demonstration boiling water reactor is scheduled to go critical early in 1963 and would thus generate the Far East's first nuclear power, beating out the first power unit—a 159-Mwe Calder type gas-cooled reactor Japan ordered from General Electric Co. Ltd. in January this year for 1964 completion.

Molotov Back, as IAEA Representative

Vyacheslav Mikhailovich Molotov, one-time Soviet First Deputy Prime Minister and long Foreign Minister, in virtual exile since 1957 as Ambassador to Outer Mongolia, has been named Soviet permanent representative to the International Atomic Energy Agency in Vienna. He replaces Leonid M. Zamyatin, recalled for reassignment. Molotov retains the rank of Ambassador, will be subordinate to Soviet atomic chief Vasily S. Emelyanov, Russian member of IAEA's Board of Governors; Zamyatin had been, and Molotov will presumably also be, alternate to the Governor. The news had diplomatic circles in a flurry of excitement, but in the final analysis the State Dept. felt the significance for IAEA is neither good nor bad but indifferent, in that Molotov as a professional diplomat will carry out the policy he is given.

Japan Delays Domestic Fuel Production

Japan's AEC has decided not to authorize tie-ups for nuclear fuel production between Japanese atomic industrial groups and foreign nuclear interests "for the time being" until fundamental fuel problems are ironed out with the U. K. AEA. (All signs point to installation in Japan of only the one Calder-type reactor now building, which needs only 62 tons' replacement fuel after the initial 186 tons bought in Britain are loaded.) Even if domestic production with foreign aid on knowhow were authorized, the reprocessing problem would remain unsolved. Therefore officials believe purchase of fuel from AEA would be more economical.

NEWS IN BRIEF

4 Industry Groups Explore New Competition Committee

Representatives of four major industry associations met in late August to explore the formation of an Inter-industry Advisory Committee on Government Competition—a group to coordinate the activities of each of the four in reducing industry-government competition in the nuclear field. Represented were the Edison Electric Institute, Manufacturing Chemists' Assn., U. S. Chamber of Commerce and National Assn. of Manufacturers; the Atomic Industrial Forum and the Machinery and Allied Products Institute were also invited but declined. Each of the attendees was to report back to his group for a reaction to the inter-industry proposal. Subject to their endorsement, the Inter-industry Committee would be formed with two representatives from each organization, plus consultants and staff.

Proposed objectives of the Committee are: 1. maintenance of liaison with government agencies to minimize government competition with the nuclear industry; 2. pooling of information on current or potential areas of competition; and 3. development of recommendations for industry programs or studies in special phases of nuclear activities.

Industry Has Mixed Reaction to AEC Patent Changes

The nuclear industry last month raised a number of objections to two proposed changes in AEC patent policy: 1. an amendment of AEC's contracting manual to permit limited patent filing abroad by AEC contractors: and 2. the charging of royalties by AEC on foreign patents it owns in countries which also charge royalties on government-owned patents (U. K., France, etc.). The industry objections to the first were much less sweeping than to the second. Generally, the industry applauded AEC's willingness to consider contractor filing overseas; but suggested it would not have much practical meaning unless AEC eliminated or modified some of its provisos. AEC felt, in turn, that its purpose to permit contractor filing may be defeated by the avalanche of industry suggestions for changes ("The trouble is industry likes the idea but they criticize it to the point where we don't get any changes.").

On AEC's proposal to collect royalties for patents it owns, industry opposition was basic: the adverse criticism ranged from fears that such a policy would spread to AEC's U. S. patents and to other federal agencies, on the one hand, to sheer disbelief that AEC would entertain such an alleged departure from public U. S. policy. "It is almost inconceivable," one industry official commented, "that this is what AEC means to do."

Explosives Bureau Suggests Fuel Transport Group

Formation of an AEC-industry committee to study and make recommendations on the safe transport of fissionable materials was suggested in late August by the Bureau of Explosives, an advisory group to the Interstate Commerce Commission. The committee is to consider fabricated and unfabricated materials, hot or cold. The Bureau's proposal was explored at a meeting Aug. 25, with 30–35 AEC and AEC-contractor representatives organizing a small committee to review details the one-day meeting could not cope with. The committee was to work out recommendations in cooperation with AEC and forward them to ICC.

Government Formally Announces Rocket Reorganization

Reorganization of the nation's nuclear-rocket program (NU, June '60, 23) was formally announced last month by AEC and the National Aeronautics and Space Administration. Harold B. Finger, head of nuclear propulsion for NASA, has assumed management of a new Nuclear Propulsion Office, reporting to Reactor Development Director Frank Pittman at AEC and Launch-propulsion Chief Donald Ostrander at NASA. Deputy to Finger is Milton Klein, formerly of AEC's Chicago Operations Office. NPO will combine and coordinate all Project Rover developmental work—previously handled by AEC's Aircraft Reactors branch under the management of Jack Armstrong—with space mission programs to be administered by NASA. The development of all nuclear reactors and components will continue to be the responsibility of AEC and NASA has primary responsibility for non-nuclear components and systems integration. With the reorganization, Finger is a "two hat" man managing both responsibilities.

Gen. Irving Branch, director of the aircraft reactors program, will continue to manage the nuclear airplane and ramjet programs. The SNAP program (systems for nuclear auxiliary power), however, was expected to go with Armstrong to a new post he has taken under Pittman, where he will manage work on advanced reactor concepts and SNAP activities.

NASA Asks Proposals on Rocket-engine Studies

Shortly before reorganization of nuclear-rocket management (*above*), the National Aeronautics and Space Administration asked industry to bid on design studies of a nuclear-rocket engine; bids were due Sept. 19. The program, a milestone in nuclear rocketry because it is industry's first crack at design work on an engine (with government funds and blessing), calls for a study of about six months, on a schedule several weeks behind the rocket flight-test studies being carried out by Lockheed and Martin (NU, Sept. '60, 27). NASA said $150,000 was available for engine studies on "a flight-test engine that is developable to a flyable engine. It might be quite crude but it would at least have the potential for application to useful systems." The winning contractor or contractors will be given a minimum of restricting guide lines. "We want a very good look at all approaches," NASA said, "and we want to be sure that no one is prejudiced as to what is possible."

JCAE Votes to Publish Amended McKinney Report

By a straight party-line vote of ten Democrats to seven Republicans, the Joint Committee on Atomic Energy decided before Congress adjourned to publish the McKinney report (NU, Aug. '60, 21) during September. The vote came after vigorous Republican questioning of McKinney on some of his conclusions and recommendations which were critical of the Administration. The 5-volume, 1500-page report will be published as "a study prepared for JCAE and is not a Committee report." It was decided that "such corrections and additions to the text as the author . . . may desire may be made prior to publication." This was taken to mean that McKinney will "clarify the language" of some conclusions and recommendations as a result of Republican objections.

Internuclear Designing Irradiator for Mines Bureau

The Bureau of Mines said last month it had selected Internuclear Corp. to design and prepare specifications for a cobalt-60 irradiator scheduled for construction next year at Albany, Ore. Internuclear was the winner over four other firms; several industry officials said there was no formal bidding. The facility, recently upsized from 100,000 to 175,000 curies, will be used for experiments with coal, oil, metals.

RADIATION NEWS

Abbott Schedules Private Radiochemical Marketing

Abbott Laboratories was to begin marketing iodine-131 last month, expecting eventually to supply a major share of the estimated 100 curies/mo used by itself and others in the U. S. Sole suppliers of radioiodine up to now have been AEC at Oak Ridge National Laboratory and Atomic Energy of Canada, Ltd. Abbott has given a purchase order to Westinghouse (for production of radioiodine in the Westinghouse Test Reactor) and was expected to give another order to General Electric (GE Testing Reactor). The iodine-131 produced in these reactors (from tellurium-130) will be marketed in sodium radioiodide solution by Abbott's Oak Ridge plant. Much of it will be used in Abbott's own radiopharmaceuticals, the rest will be available for sale to other radiopharmaceutical firms and for use in tracer studies.

AEC, greeting the Abbott decision with mixed feelings, welcomed a private producer into the business and said it would cut down its radioiodine production as Abbott began to meet the demand. There was some doubt, however, as to AEC's giving up radioiodine production completely, in favor of only one U. S. producer, plus the Canadians. Abbott estimated its price for radioiodine would run about 20% less than AEC's, reflecting both a lower charge and a different method of calibration. The company says it is considering eventual production of other radioisotopes but has no concrete plans as yet.

AEC Orders Study of Mixed Fission Products for SNAP

General Instrument Corp., Newark, N. J., is exploring the use of mixed fission products as relatively inexpensive heat sources for small power devices. AEC awarded a Phase 1, $40,000 contract to General Instrument under its SNAP program (systems for nuclear auxiliary power), which has branched out from outer-space technology utilizing isotopes to such things as navigational aids for the Navy and Coast Guard (NU, Sept. '60, 28). Phase 1, scheduled to be completed about Nov. 1, calls for four areas of study: 1. comparison of various techniques for fixing mixed fission products in solids; 2. life and utility characteristics of various thermoelectric conversion materials which might be used in such a generator; 3. conceptual design and parametric analysis of the heat source; and 4. possible uses for a mixed-fission-product generator (two now under consideration include power sources for underwater anti-submarine-warfare applications and navigational aids). If AEC continues to support the work beyond Phase 1, it is expected to lead to a demonstration unit of up to 5 watts after another year of work. Such a device is not considered feasible for space power because of its low specific power output and the demand for extra shielding imposed by strong gammas.

3M Developing New Encapsulating Idea for Isotopes

A ceramic coating technique for radioisotopes in tiny spherical form has been developed by Minnesota Mining & Manufacturing. The technique chemically seals the isotope in ceramic spheres of 10–100 microns, rendering it inert and thus metabolically safe in human ingestion, the company feels. Leaching tests in 0.01 normal hydrochloric acid removed less than 0.01% of the radioactivity in seven days. A wide variety of isotopes, including alpha emitters, can be incorporated in the Microspheres at virtually any level of activity, although 3M is concentrating on low-level uses initially. The Microspheres have been going through various evaluation tests commercially, including experimental use in luminous dials, process-control systems and medicine (internal cancer therapy and blood tracing). First major commercial order was expected in late summer or early fall.

For use on timepiece dials, Microspheres of promethium-147 would be combined with a phosphor (zinc sulphide is preferred) via an organic binder; a .003-in. layer of this is coated on the surface to be illuminated, then a second .003-in. layer of phosphor and binder is applied. Any plus-charge isotope can be thus contained in the Microspheres, with luminescence coming from radiation-excitation of the phosphor crystals and the two layers cutting down surface radiation. The Microspheres also hold promise for static elimination, guaging and other process-control applications for both safety and psychological reasons: there is little or no danger in accidental ingestion and the ceramic coating reduces the danger from fire.

Martin, Air Reduction Considering Partnership

Construction of the first private radioisotope separations facility in the world is under serious consideration by Martin Co. and Air Reduction Co., which would form a new company to build and operate it. Possible formation of the partnership had been indicated earlier this year (NU, Apr. '60, 31) when Martin estimated that a large separations plant could be built for $10–$12-million and that it could produce strontium-90 for 35–50 cents/curie, or one-tenth AEC's prices. Both of these estimates held up under subsequent study. The two firms would produce strontium-90 and cesium-137, primarily, with cerium-144 a third possibility; plant construction would take 2–2½ years.

Martin and government officials alike pointed out that several major problems face the project. In effect, Martin-Air Reduction would ask the government to approve their entry into one of several steps of the isotope recovery process, with AEC furnishing the feed material and buying back most or all of the separated isotopic material. Martin-Air Reduction would have to work out a price acceptable to the government and make arrangements for locating their plant on AEC-owned land (Hanford is the preferred location) or near Hanford if a site on the reservation were not available. AEC officials are divided on the propriety of having private activity in the separations program at Hanford—some heartily in favor of having private industry in the picture, others against it. Also, Hanford has its own plans for expanding its separations capability.

AEC Lowers Cobalt-60 Minimum to $1/curie, a 50% Cut

AEC last month reduced to $1/curie its minimum price for cobalt-60, in a move which may provide some impetus for commercial, high-level use of cobalt. In a general reduction of cobalt-60 prices at all levels of activity, AEC cut the former minimum of $2/curie (1–10 curies/gm specific activity) in half—reducing it to $1/curie for more than 25,000 curies of 1–25 curies/gm activity. Effective Sept. 15, the new price schedule is: 1–25 curies/gm, $2/curie; 26–40 curies/gm, $3; 40–55 curies/gm, $4. These quantity discounts were established: 25% for quantities of 5–25,000 curies; 50%, 25–100,000 curies; and a flat $1/curie for all amounts greater than 100,000 curies, regardless of activity.

Brazil Orders Cobalt Research Irradiator from C-W

Brazil last month ordered a $323,000, 30,000-curie cobalt-60 irradiator from Curtiss-Wright Corp. The research facility will be used chiefly for extending shelf-life of perishables (meats, fish, etc.) for short periods—as little as a day or two.

AEC Lowers Limits On Radiation Exposure

Modified and moderated since a first version aroused a storm of industry protest a year ago (NU, Sept. '59, 21), a new version of AEC's regulations on protection of atomic employees and the public against radiation overexposure was promulgated last month. They are scheduled to go into effect Jan. 1.

In their original form last year, the proposed rules would have cut permissible average external exposure from 15 to 5 rems/yr. The new version has the same over-all result, but provides exceptions and alternatives for industry. A basic table sets out maximum exposure levels for radiation workers: 1¼ rem/calendar quarter whole-body exposure (and head, trunk, blood-forming organs, eyelenses and gonads); 18¾ rem/quarter to extremities, 7½ rem/quarter to skin.

This schedule must be followed if the employer does not choose to dig back into the complete medical history of the individual employee. If, however, the record is available and supports it, then a higher exposure—80% of the limit presently in effect—is permissible: 3 rem/quarter provided no more than $5 \times (n\text{-}18)$ rem total accumulated where n is the age of the individual (the NCRP formula, NU, Jan. '57, R3).

Another Relaxation

A second major softening of last year's proposed version of the rules is that the mandatory annual report on his exposure to each employee is dropped. Instead, reporting is required only on request of the employee, annually or on termination of employment; mandatory reporting is retained in cases where permissible limits are exceeded. A new requirement is that employers must post notice to employees outlining the provisions of the regulation, the responsibilities of employee and employer, and the rights of the former. This regulation will cover all AEC licensees. Industry comments are welcome, but AEC hopes no changes will be needed.

Industry's objections to the original version a year ago centered on contentions that the lower permissible exposure would be so restrictive as to vitiate the technological advances based on use of radiation, and that the mandatory reporting would arouse new fears of radiation rather than allay any existing ones.

NUCLEONICS Statistics of the Quarter

Costs of U. S. Civilian Reactors in Progress (10^6)†

	Total Cost of Projects	Costs, '60 2nd quarter	Costs thru 6/30/60	Still to be spent
Power prototypes & experiments	**762.8**	**51.5**	**337.9**	**424.9**
—Research & development:				
AEC	133.1	7.7	76.9	56.2
Electric utilities	49.9	1.9	28.9	21.0
—Plant & equipment:				
AEC	141.1	11.0	46.4	94.7
Electric utilities	345.6	26.4	173.1	172.5
—Fuel fabrication:	37.2	1.5	8.0	29.2
AEC	10.7	0.4	2.8	7.9
Electric utilities	26.5	1.1	5.2	21.3
Savannah propulsion plant	**29.0**	**1.8**	**14.7**	**14.3**
Research & test reactors	**122.6**	**6.6**	**71.3**	**51.2**
AEC	79.1	4.0	39.1	40.0
Other govt. agencies	15.8	1.3	13.6	2.2
Manufacturers & universities	27.7	1.3	18.6	9.1

	Latest month	Month ago	Year ago
Nuclear Contracts *—			
Contracts awarded for public projects (10^3)	6,514	1,555	2,347
Proposed construction, privately-owned (10^3)	0	0	0
Contracts awarded, private work (10^3)	0	0	0
Backlog of private projects (10^3)	287,549	287,549	285,549
Isotope Use †—			
Applications for isotope use	624	565	535
Cumulative total of isotope users	5,798	5,747	5,187
ORNL shipments (curies)	22,880	4,092	24,376
Public and private export shipments	110	418	311
Employment †—			
AEC employment	6,830	6,835	6,750
Construction and design contractor's employment	12,076	11,199	9,355
Total operating contractors employment	116,666	104,612	105,928
Production workers	51,024	51,140	51,967
Research and development employees	49,883	49,141	49,217
Miscellaneous workers	3,683	4,331	4,744

U. S.-built Reactors ‡—

	Operating	Building	Contracted
Power, domestic	3	9	5
Power, for export	0	5	1
Power experiments and pilot plants	6	7	1
Military and naval	23	38	14
Research and test, domestic	68	19	52
Research and test, for reports	19	20	5
Total	119	98	78

Foreign-built Reactors ‡—

Power, domestic	18	21	75
Power, for export	0	3	1
Research and test, domestic	41	6	13
Research and test, for export	9	6	0
Total	68	36	89

* From *Construction Daily*, a McGraw-Hill periodical † From AEC ‡ NUCLEONICS figures

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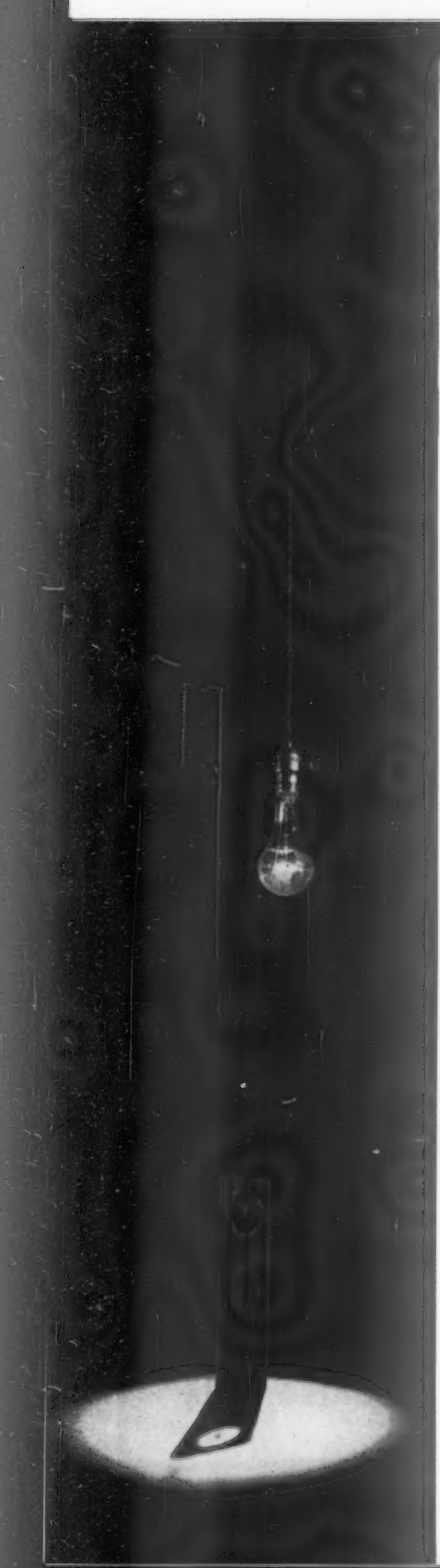

One of a series

New Light on a Compound Semiconductor

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Still in the early experimental stage, this phototransistor is a tangible result of the General Motors Research Laboratories' program on semiconductors — particularly the group II-VI compound, cadmium sulfide. Behind its development lies the steady accumulation of (1) know-how in crystal growing, doping, and contact preparation and (2) information about CdS's intriguing solid state properties (red or green luminescence, high photoconductivity, short relaxation times, etc.).

For the researcher, this three-terminal device is adding a new dimension to the fundamental understanding of semiconductors. For instance: GM Research scientists have uncovered the important role of photo-generated holes in modulating the conductance of this intrinsic semiconductor and have determined the hole drift mobility through a new theoretical analysis.

These semiconductor investigations illustrate the dual aim of GM Research: contributions to the science, advances in the technology of important new subject areas. Such research is the initial step in General Motors' continuing quest for "more and better things for more people."

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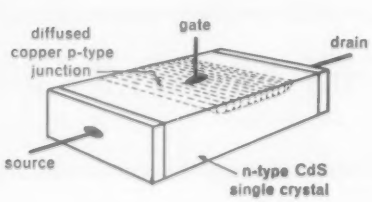

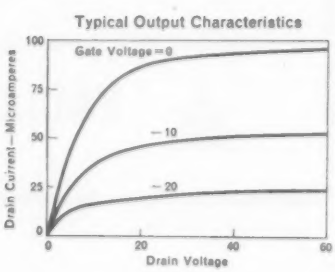

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GRAPHITE, with its high temperature capabilities, goes far to meet these needs, but in its usual form it is too permeable to the passage of fission gases at the temperature concerned.

HAWKER SIDDELEY, in collaboration with DRAGON, U.K.A.E.A. and R.A.E. Farnborough, have now developed an impregnation process which has resulted in large reductions in permeability, even at the high temperatures involved in DRAGON.

Today's nuclear developments are tomorrow's industrial necessities.

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Bursting Discs · Chemical Plant · Crucibles · Electrodes
Gland Seatings · Heat Exchangers · High Temperature
Bearings and Bushes · Hot Pressing Dies · Nuclear Fuel Cans
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THE HEART OF THE DRAGON

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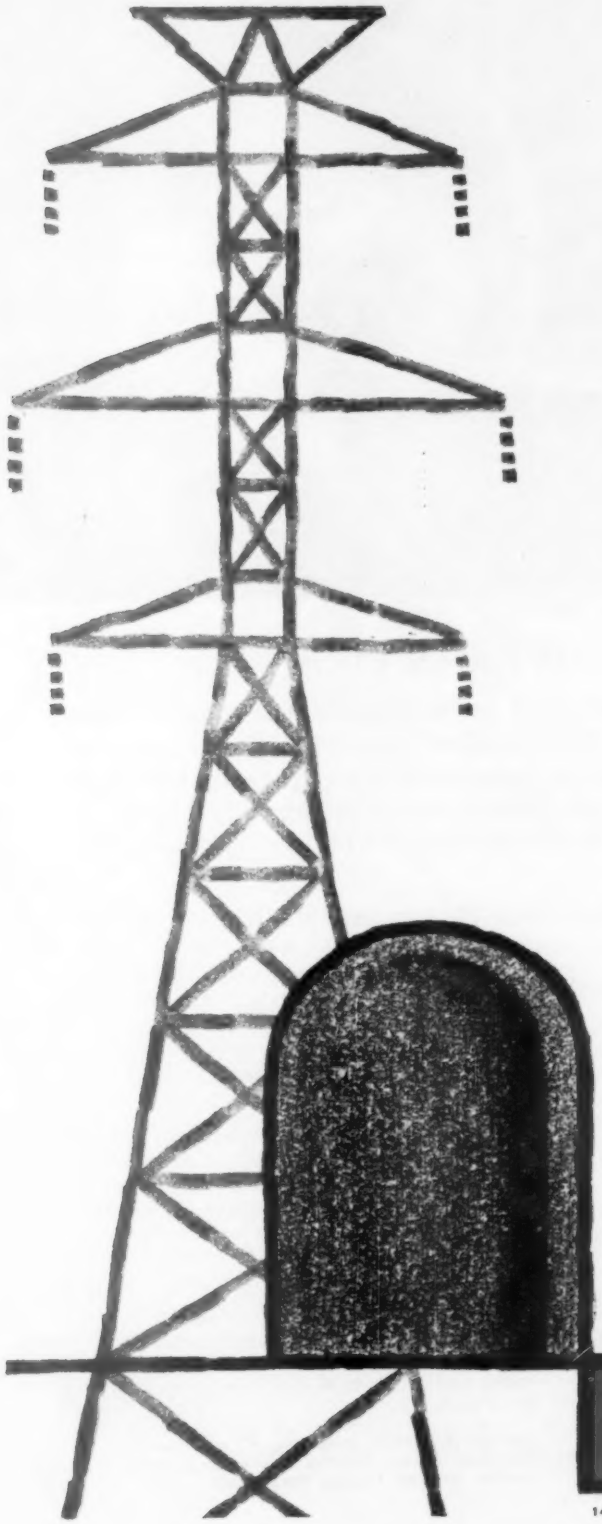

Design Engineering for

NUCLEAR POWER

With a background of 69 years of providing consulting service to the electric utility industry for conventional electric generating capacity, Sargent & Lundy has now developed an extensive experience in the nuclear power field. The firm's nuclear activities started with the historic Borax III installation at Arco, Idaho and have continued through the design of the EBWR Facility at Argonne National Laboratory, the Elk River Reactor Project and the current design of a Process Heat Reactor Project to be constructed near San Diego, California. In these and other projects, Sargent & Lundy is devoting its capabilities to the progress and development of the nuclear power industry!

An outline of experience

- Turbine Installation for the Borax III Experimental Reactor Facility
- Experimental Boiling Water Reactor Facility including revisions to permit 100 MWt operation
- Elk River Boiling Water Reactor Facility
- Experimental Low Temperature Process Heat Reactor Project
- Containment for Belgian Pressurized Water Reactor
- Design Study of Heavy Water Moderated Power Reactor Plants
- Conceptual Design of 50 MWe Prototype Boiling Water Reactor Plant
- Design Studies of Saturated and Superheated Boiling Water Reactor Plants
- Study of Containment Costs

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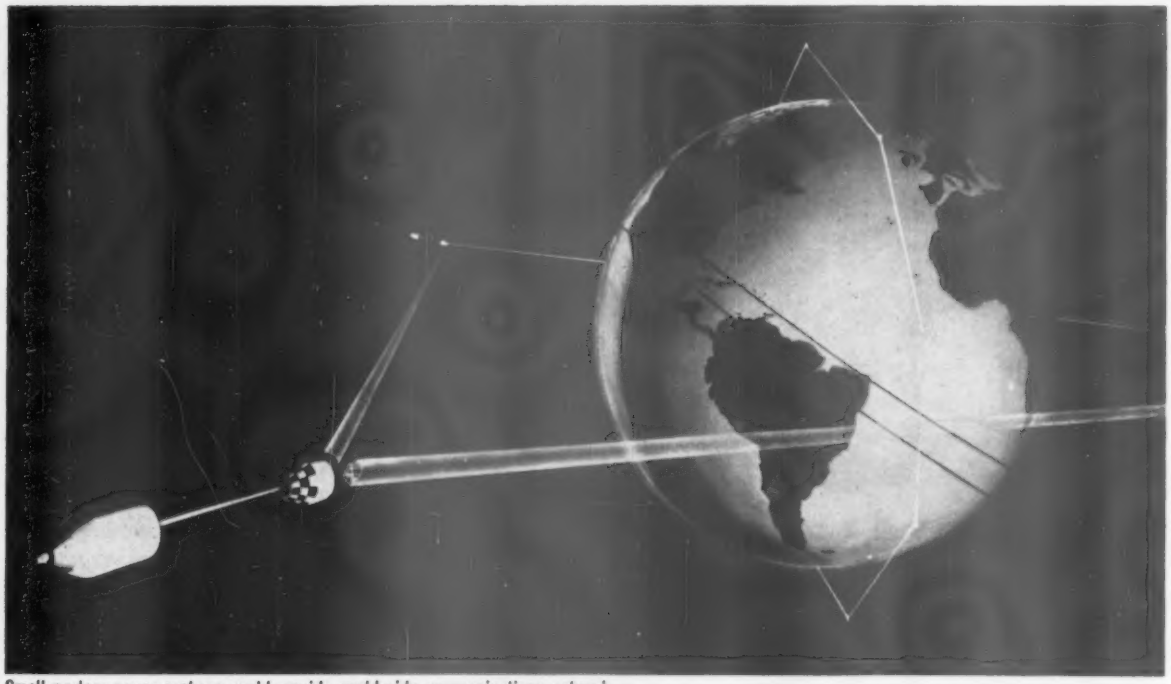

Small nuclear power systems could provide world-wide communications network.

NUCLEAR POWER IN ORBIT

At this moment engineers and scientists at Atomics International are extending the boundaries of present day technology to provide this country with lightweight, long-life auxiliary power systems for outer space applications. These systems must be light in weight, fully automatic, completely reliable... yet must provide thousands of watts of electricity for periods up to one year without maintenance.

We need creative engineers and scientists to help us provide this new source of auxiliary power for outer space.

IMMEDIATE OPPORTUNITIES ARE AVAILABLE IN:

STRESS ANALYSIS. Degree plus five or more years of experience either in thermal stress or dynamic stress resulting from shock and vibration loads in aircraft structures. Responsibilities will entail design support for compact nuclear power plants for space applications, including review of all designs with respect to stresses resulting from thermo gradients and transients, static loadings, and vibrational and shock loadings.

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SHIELDING ANALYSIS. Analysis of thin shield systems using high speed computers. Proposal of experiments to substantiate calculations and analysis of test results. Degree and three to five years experience required including an understanding of Monte Carlo methods.

THERMOELECTRIC. Electrical engineer with one or more years experience in the development of thermoelectric equipment to originate and develop advanced, light weight thermoelectric equipment for use with compact nuclear power plants for space and other mobile applications.

HEAT TRANSFER. Senior engineer to be responsible for system engineering studies on the thermal, hydraulic and thermodynamic performance of compact power reactor systems.

For specific details write: Mr. C. K. Newton, Personnel Office, Atomics International, 8900 DeSoto Avenue, Canoga Park, Calif.

ATOMICS INTERNATIONAL
A DIVISION OF NORTH AMERICAN AVIATION, INC.

PICKER NUCLEAR

announces a new line of

***transistorized* NUCLEAR TRAINING INSTRUMENTS**

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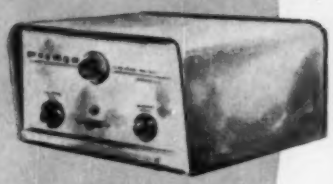

TRAINING ANALYZER

TRAINING SCINTILLATION DETECTORS

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PICKER QUALITY AT "BUDGET" OUTLAY

Picker Nuclear announces a comprehensive line of basic instrumentation for training students in radioisotope technics. Uniquely versatile, these instruments permit the scheduling of full laboratory courses in radioisotope technics (including such important fields as pulse height analysis and rate function studies).

The cost of this new equipment falls well within the reach of modest equipment budgets. Instruments can be delivered before the start of the 1960-61 academic year. For details, please call any local Picker office (see 'phone book) or write Picker X-Ray Corporation, 25 South Broadway, White Plains, New York.

Hallmark of quality nuclear instrumentation

Picker nuclear

Standing behind every Picker instrument is a local member of the Picker X-Ray national sales and service network.

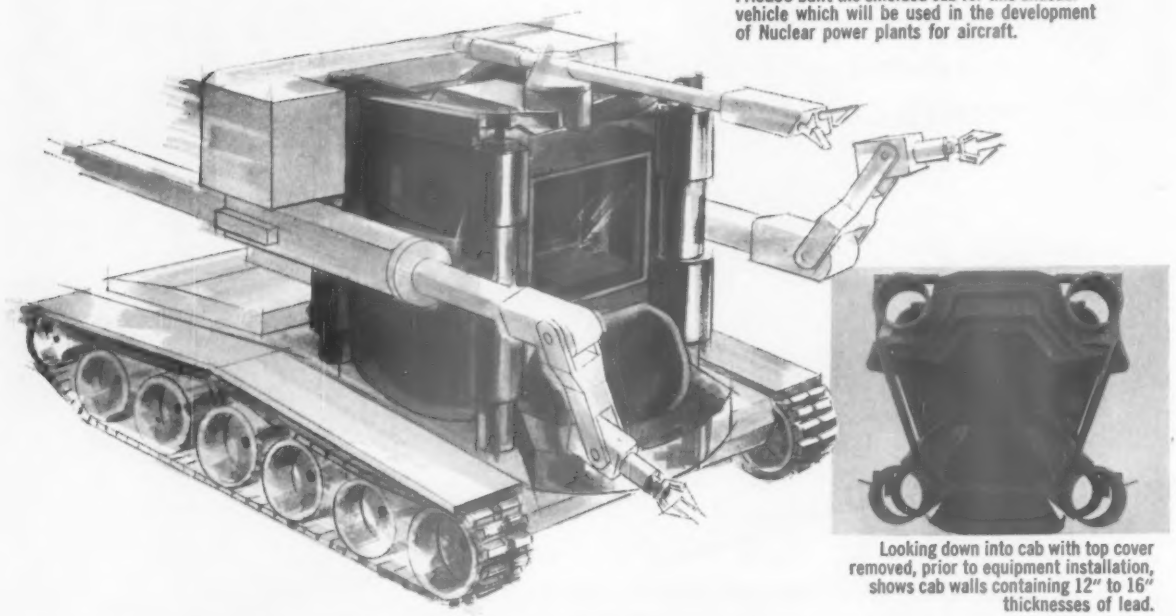
He's there to protect your investment.

Because of him the user of a Picker instrument is never left stranded.

CONSULT PACECO

OUTSTANDING SOURCE FOR GAMMA SHIELDING

PACECO built the shielded cab for this unusual vehicle which will be used in the development of Nuclear power plants for aircraft.



Looking down into cab with top cover removed, prior to equipment installation, shows cab walls containing 12" to 16" thicknesses of lead.

One complete Service—One Responsibility *

***CONSULTATION** PACECO can assist you in selecting the most efficient and economical equipment design for your project. Rare experience developed while equipping Nuclear projects of the AEC and private industry during the past 12 years, assures better equipment when you consult PACECO at the planning stage.

***DESIGN** From your basic specifications, PACECO develops the final product most suited for your requirements. 37 years experience in the design of heavy fabrications enables PACECO to serve you with better designs resulting in lower first costs and more efficient equipment.

***FABRICATION** Complete facilities plus experience make PACECO unique in ability to fabricate heavy equipment to close tolerances. The 85,000 lbs. shielded cab illustrated above has tolerances of ±.005 of an inch—a usual, rather than unusual, specification for PACECO. Literally hundreds of unit parts were combined into weldments during the fabrication of this shielded cab. The finished product encases within its walls, protective lead 12" to 16" thick.

***GAMMA PROBING-TESTING** PACECO offers a complete probing and testing service; Spectrometer—Gamma Probe for Gamma Shield Inspection of material; Gammagraphing; Helium Leak Testing; Ultra-sonic Testing of Lead Bond; as well as X-Ray, Magnaflux and other standard testing methods.

PACECO is an INSMETAL licensee. INSMETALS are Lead-Surfaced Metals with few if any fabricating limits. They combine the excellent gamma shielding attributes and fine corrosion values of Lead with well-known properties of Aluminum and its Alloys in BAUXILUM; Copper and its Alloys in CUPRALUM; Carbon Steel in FERROLUM; Stainless Steel or other Nickel Alloys in NICROLUM; and Stainless Clad Carbon Steel in FERRO-NICROLUM.—Send for brochure.

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BIG—BUT TAKEN IN STRIDE BY B-L-H's FABRICATING TEAM

Fabricating jobs like the nuclear reactor being installed for the AEC at Hallam, Nebr., are no strangers to B-L-H. We have handled such tasks many times.

To get an idea of what's involved, note these facts about the Hallam reactor:

Reactor vessel

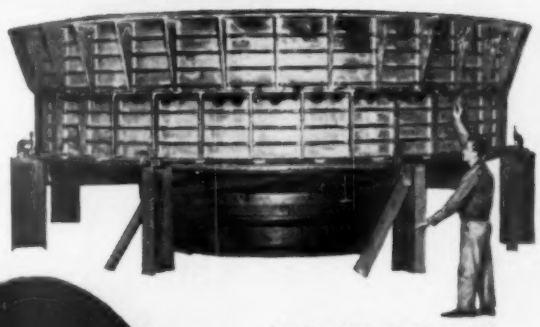
- 19 ft. in diameter, 33 ft. high, welded of Type 304 stainless steel
- Metal thickness range from ¾ to 2 in.
- All material subject to ultrasonic inspection; all welds inspected radiographically, also with dye penetrant and helium leak detection equipment

Reactor containment vessel

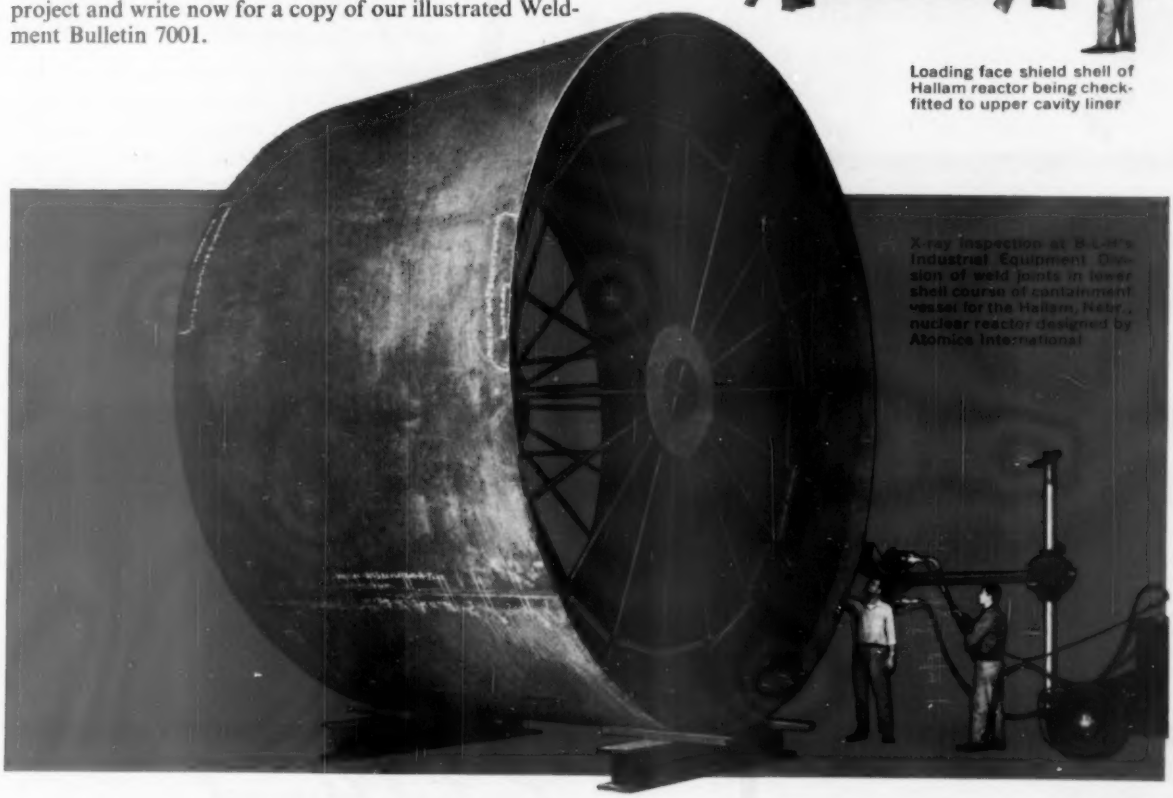
- 21 ft. in diameter, 36 ft. high
- Bottom head fabricated of carbon-silicon steel, main barrel section of chromium molybdenum steel
- All welds radiographed, bottom head section stress relieved

Keep in mind, too, the fact that for parts as large as these —and with the limited amount of machining—the tolerances call for highest accuracy in fabrication.

Handling big fabricating jobs economically and efficiently is our stock in trade. So take advantage of our exceptional experience and competence. Consult us about your next project and write now for a copy of our illustrated Weldment Bulletin 7001.



Loading face shield shell of Hallam reactor being check-fitted to upper cavity liner



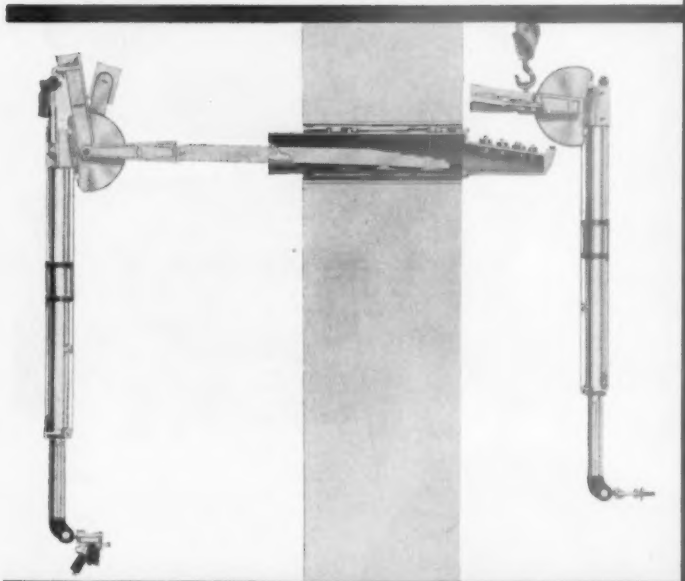
X-ray inspection at B-L-H's Industrial Equipment Division of weld joints in lower shell course of containment vessel for the Hallam, Nebr., nuclear reactor designed by Atomics International

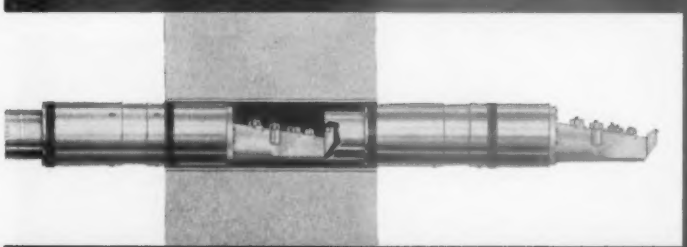
BALDWIN · LIMA · HAMILTON

Industrial Equipment Division · Philadelphia 42, Pa.

NEW . . . for high-level alpha-gamma hot cells—for handling pyrophoric, highly toxic gaseous or airborne particulate materials—wherever complete atmospheric control, prevention of dissemination by explosion or other accident is essential . . .

complete containment is provided by central research model A sealed manipulators





Sensitive and reliable, Model A manipulators are designed for dextrous, positive control and complete containment with shielded enclosures.

CONSIDER THESE IMPORTANT FEATURES:

SEALS—Double rotary mechanical seals between master and slave mechanisms insure reliability. Space between seals may be pressurized to monitor seal integrity. One seal is always operative even when changing seal tubes. "Push-thru" seal-tube replacement technique does not require complete wall port opening. Seal-tube features mean that all contaminated assemblies remain inside cell for disposal or decontamination and need never be brought out to the operating face.

OPERATION—Careful counterbalancing, reduction of mass, friction and lost motion make forces in the ounce range sufficient to initiate all motions. Easily handles 20-pound load per arm. Bilateral drive and force reflecting design characteristics give remarkable "sense of feel," reducing training time to a minimum.

MAINTENANCE—Three standard, interchangeable subassemblies: master arm, slave arm, and seal tube, simplify maintenance. A crane and simple fixture are sufficient for remote connection or removal of slave arm. Alignment pins assure positive slave arm positioning. All slave-end motions lock at disengagement for easy relocation.

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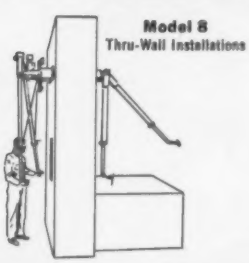
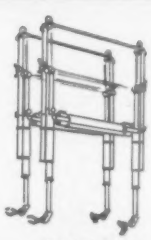


Model 8
Thru-Wall Installations

Model 7
Restricted Space Installations

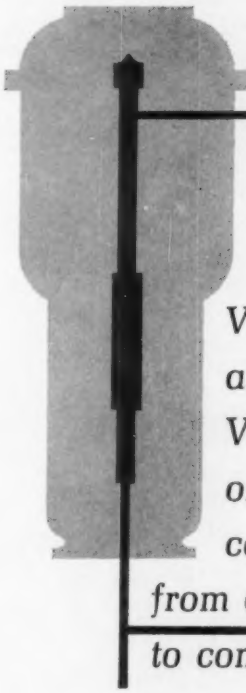


Model 4
Over-Wall Installations

Model B
Canal Manipulator

For further information write:

Central Research
laboratories, inc.
Red Wing, Minnesota, Dept. 110



■ *In-pile loops are*
tough engineering problems.
Look at the ETR in Idaho:
Vitro designed three test loops
and a 2 Mw experimental cooling loop.
Vitro's design staff, alone
or teamed with reactor specialists,
can do the whole nuclear job
from critical experiment
to completed power plant. ■

Vitro

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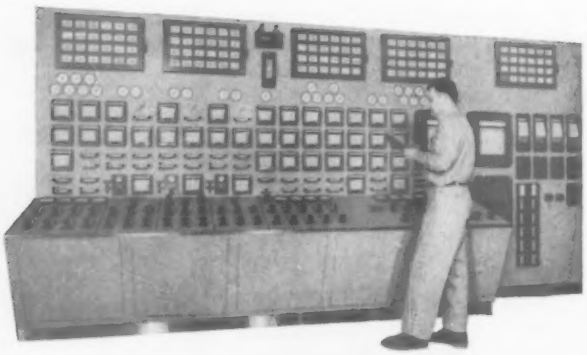

Foxboro control console . . . designed and built as a single unit — for Public Service of New Hampshire, Bow Station

a bold concept in central station instrumentation

Central station control room panels have looked pretty much the same in generating stations built in the past decade. Now, The Foxboro Company introduces a dramatic new concept in control room instrumentation.

Called the "Consotrol Approach," the new system blends the separate instrument panel and the separate operator's console into a single, integrated operating unit. The expense of transmitting variables to the panel *and* to the console is eliminated; control room size is reduced; plant operation is simplified.

But what makes the new system really pay off is its use of small-case Consotrol* electronic and pneumatic recorder-controllers. These unique Foxboro instruments are so compact that *four* can be mounted in the panel space required for a single large-case recorder. Result: control panels which would normally run up to 50 feet in length, can now be erected in a fraction of the space — and at a fraction of the cost.

At a time when instrument outlay accounts for as much as 10% of new construction costs, the Foxboro Consotrol Approach is particularly worthy of close Industry investigation. For more complete details write The Foxboro Company, 6210 Neponset Avenue, Foxboro, Massachusetts. Ask for Bulletin 1-17.

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Timely? Many complex factors shape the final decision to proceed with your expansion plans...and timing is an important one. Independent analysis of all aspects of your proposed program is the *Pre-Engineering* service offered by Kaiser Engineers. The studies and evaluations furnished by KE Pre-Engineering represent only one phase of total KE services. Kaiser Engineers designs and builds all types of power plants—steam-electric, gas turbine, combined cycle, nuclear, and hydro-electric. From Pre-Engineering through design and construction, Kaiser Engineers provides complete, one-company service and ingenuity based on years of experience.

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Facilities exist for fabrication to individual requirements.

FUEL FOR THE NEW INDUSTRIAL REVOLUTION

The Rio Tinto Group, with uranium interests in Canada, Europe and Australia, is geared to meet the uranium needs of refineries, fabricators, nuclear power plant manufacturers and operators through the important nineteen sixties and beyond.

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Type of Stacking Patented by French C.E.A.

An improvement in Pechiney Beryllium.

Pechiney is now in a position to observe the following limits on impurities in its Beryllium in flakes:

Carbon 300 ppm maximum • Aluminum 300 ppm maximum • Silicon 300 ppm maximum • Iron 300 ppm maximum • Nickel 200 ppm maximum • Calcium 200 ppm maximum • Sodium 300 ppm maximum • Halogens 1,100 ppm maximum (Expressed as Chlorine) • Oxygen 2,500 ppm maximum (Determined by precipitate in Bromated Alcohol)

Pechiney is at your disposition to help you solve technical problems concerning the use of Beryllium in various areas of application.

PECHINEY Division Applications Atomiques

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TITAN—*50 miles up: Official USAF Photo*

Air Force-Martin Titan, *giant American ICBM, has been chosen for a key role in space exploration. One of its first missions will be to launch USAF Dyna-Soar — manned aerospace craft.*

MARTIN

NUCLEAR CANADA

. . . Its Importance to You

Canada's atomic energy program has an importance that transcends Canada's boundaries. Its importance is well recognized by the U. S. nuclear engineers and scientists who have journeyed to Chalk River to take advantage of the superb capabilities of the NRX and NRU research reactors there. Certainly it is recognized by the Indian scientists who, with their Canadian colleagues, recently brought to criticality the Canada-India Reactor, an improved NRX-type built near Bombay jointly by the two countries.

Why is the Canadian program so highly regarded and so closely followed? For one thing Canada leads the world in exploring the natural-uranium-fueled heavy-water-moderated power-reactor concept. This reactor type fits very well into the nuclear economy of Canada, which has vast uranium resources and yet does not have a capability for enriching the uranium. It can fit equally well into the economy of any country that does not want to be dependent on enriched uranium from abroad.

Canadian engineering is of high quality, and high-neutron-economy heavy-water reactors place great demands on that capability. The Canadians must make every neutron count; every fractional diminution of reactivity is carefully weighed. There's no such thing as upping the enrichment of the fuel to be used—the Canadians are committed to that 0.715% U^{235} in natural uranium. There's much more reliance on tests, much less reliance on "fudge factors" when each mil of thickness added to the pressure tubes in a reactor is also being measured in terms of the effect it will have on power costs. The Canadians have led, too, in supporting a more quantitative approach to safety problems (see p. 73), and they have not regarded containment vessels as sacred.

Organizationally the Canadians have something to teach us, too. Perhaps it's easier with a smaller, unidirectional program, but it certainly is striking how much less of a "crisis" atmosphere one feels in the Canadian atomic establishments, industrial as well as governmental.

Canadian capabilities have received new recognition in the new U. S.–Canadian cooperative program for development of heavy-water reactors. In addition to a broad mutual exchange of personnel and information the U. S. has appropriated $5-million for a research and development program "to be specifically directed towards the heavy-water-moderated reactors to be built by Canada."

Because we too feel that the Canadian effort is important we have devoted this issue of NUCLEONICS to Nuclear Canada. We hope you share our conviction and will benefit from reading Canadian points of view as we have benefited from the act of bringing them to you.

—The Editors

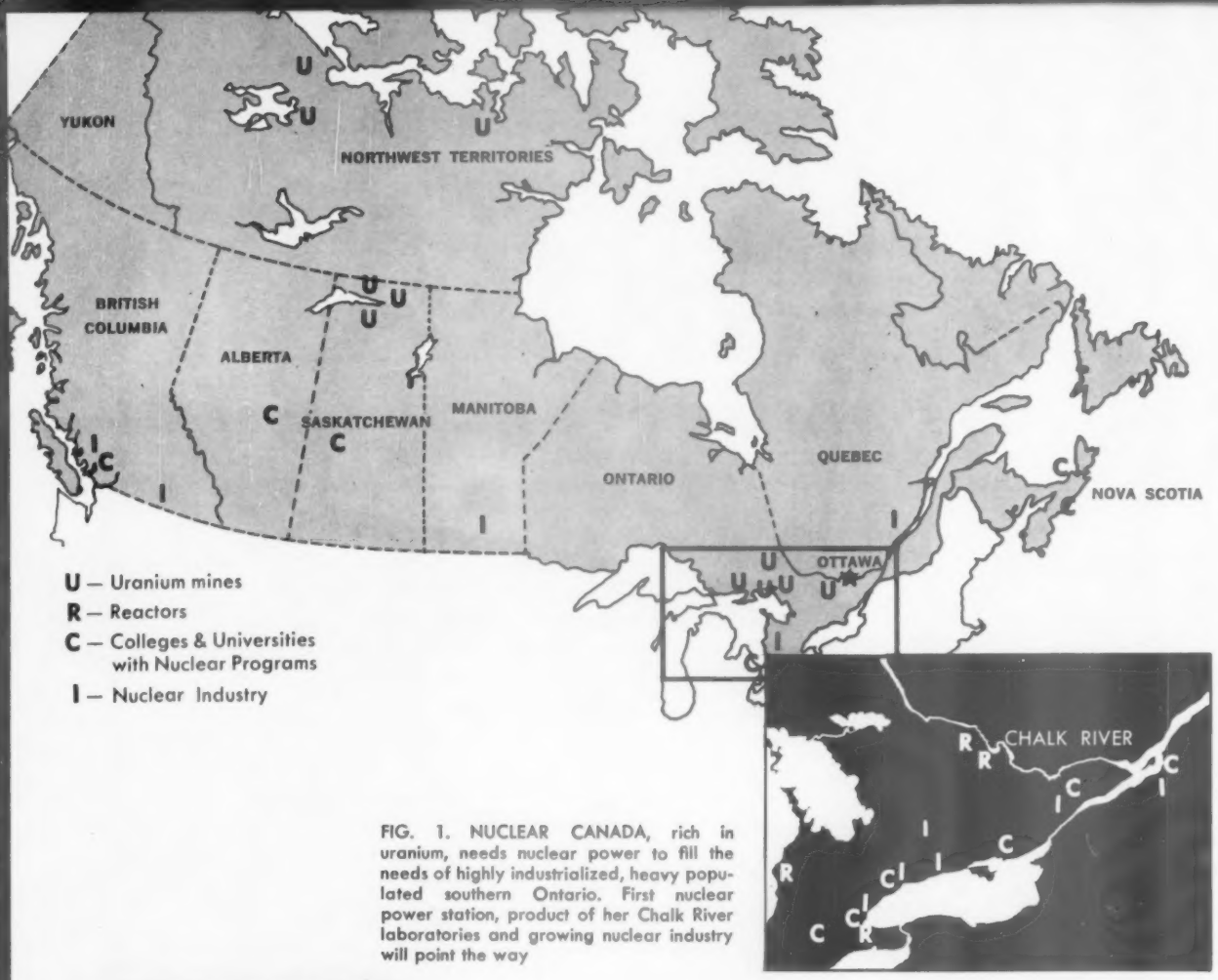


FIG. 1. NUCLEAR CANADA, rich in uranium, needs nuclear power to fill the needs of highly industrialized, heavy populated southern Ontario. First nuclear power station, product of her Chalk River laboratories and growing nuclear industry will point the way

NUCLEAR CANADA at a Glance

A GLANCE AT THE MAP above tells much of the story of nuclear Canada, of why this country is engaged in an atomic-energy effort of major size. For Canada is rich in uranium and has exhausted her hydroelectric potential in heavily populated, highly-industrialized southern Ontario (see inset). New power for the Ontario Hydro Electric Power Commission's grid can only come from fossil fuel imported from U. S. coal fields across Lake Erie or from Canada's own uranium. Helping nuclear power is the fact that capital charges are low for the publicly-owned Ontario Hydro, helping too is Canada's strong nuclear tradition and growing nuclear industry.

Canada's atomic energy program is organized differently from that of the U. S. (see Fig. 2). Atomic Energy of Canada Ltd., is the governmental organ for the exploitation and promotion of atomic energy. A second body, Eldorado Mining and Refining Ltd., is charged with the purchase of uranium from mines and mills and its processing at a refinery in Port Hope. Both Eldorado and AECL are so-called Crown companies—this means that their shares are held by a Minister of the Crown in trust for Her Majesty the Queen and that they can act only as agents of the Crown. In all other senses they function as any other company and, in particular, can (and do) engage in profit-making activities. The Atomic Energy Control Board is responsible for regulatory matters. Thus, the Canadians have, in principle, that separation of regulatory and promotional obligations which many have called for in the U. S. program.

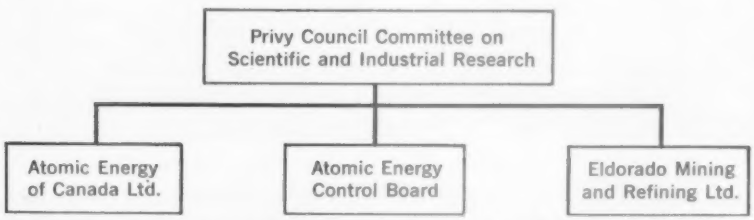

Privy Council Committee on Scientific and Industrial Research
Atomic Energy of Canada Ltd.
Atomic Energy Control Board
Eldorado Mining and Refining Ltd.

FIG. 2. GOVERNMENT ORGANIZATIONS responsible for atomic energy in Canada

The Atomic Energy Control Board,

like the U. S. AEC, has five members, but there the similarity stops for the entire full-time professional supporting staff consists of one legal advisor and two scientific advisors. Its budget of $706,000 divides into two pieces: $650,000 for grants to universities for nuclear equipment and research and $56,000 for its own modest administrative expenses. To help it carry out its regulatory work the Board makes use of personnel of the Federal and Provincial Health departments. In addition, AECL personnel act as advisors to the Board in connection with licensing and standards problems.

Relations between the crown companies and the Control Board are very close—J. L. Gray, president of AECL, is a member of the Control Board as is W. M. Gilchrist, president of Eldorado. (The president of the National Research Council is, *ex officio*, another member, providing a tie to still another organ of nuclear research in Canada.) The head offices of all three organizations are in the same building in Ottawa. And all three report to the Honourable Gordon Churchill, Minister of Trade and Commerce, in his capacity as chairman of the ministerial-rank Committee of the Privy Council on Scientific and Industrial Research.

Atomic Energy of Canada Ltd. is a much larger and more complex organization than the Control Board. It has 2300 employees and an annual budget that runs slightly over $32-million. The principal activities of AECL are at Chalk River, where the research and development activities are centered but there are also substantial groups in the Nuclear Power Plant Division at Toronto and in the Commercial Products Division at Ottawa. NPPD is responsible for design of Canada's first full-scale (200-Mw) nuclear power station, CANDU, and supervises projects being carried out under contract such as NPD-2, the 20-Mw prototype for CANDU. CPD sells (for profit) radioisotopes and high-activity irradiators.

Industry's Role

Even as the Atomic Energy Act of 1954 was the Magna Carta for the U. S. atomic industry so AECL invitations to participate in NPD-1 in 1954 gave Canadian firms the green light for getting into the nuclear business. Some of the early entries have dropped out but enough are left and prospects for a healthy industry are sound enough that this year saw the formation of a Canadian Nuclear Association (see p. 23 for story).

The three leading Canadian nuclear companies in terms of volume of nuclear business are all offshoots of U. S. firms. Canadian General Electric Co. (Peterborough) is first among the three, followed by AMF Atomics (Port Hope) and then by Canadian Westinghouse (Toronto).

CGE's dominant sales position reflects its having gotten AECL contracts for the design, development and construction of the $32-million NPD power prototype (to whose costs CGE contributed $2-million) and for the design of OCDRE, an experimental organic-cooled D_2O-moderated reactor for which CGE provided the concept. CGE's fuel-fabrication facility works overtime making Zircaloy-clad uranium oxide fuel for NPD's first core (value $2-million).

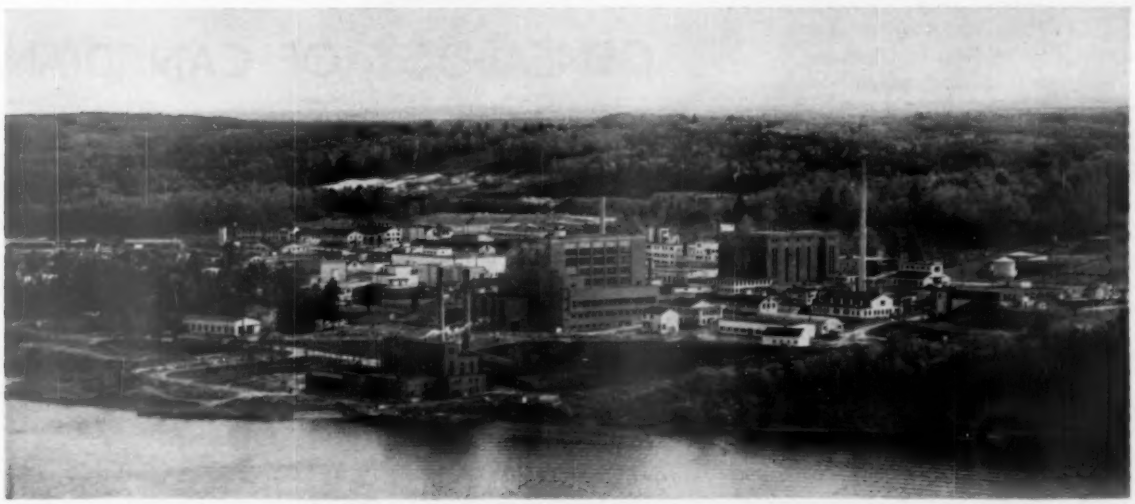
AMF Atomics, Ltd. (Port Hope), while solely a fuel fabricator (they provided the pool reactor for McMaster University but only as agents for AMF Atomics Division of the U. S. American Machine & Foundry), is perhaps the only one of the three whose operation is profitable. They hold the contracts for supplying metal fuel for NRX and NRU (which produce plutonium for the U. S. while they produce neutrons for research) through 1964. Recently they consummated the first all-commercial fuel contract in Canada—for Japan's JRR-3 heavy-water research reactor. They share with CGE fuel development for CANDU.

Canadian Westinghouse (Hamilton) seems to have its main strength in the design and fabrication of in-pile test loops—they've built several for NRU and the U. S. Westinghouse Testing Reactor. Materials studies—in particular on zirconium alloys and beryllium—are another forte. They recently completed a study for AECL of the feasibility of package power reactors for the North of Canada—but the essentially negative conclusions of that report mean no follow-on business for Westinghouse in that department. Company officials are frankly admitting they're keeping their operation small until nuclear power is a bigger thing in Canada.

Also waiting in the wings is Orenda Engines, Ltd., hungry for business because of cutbacks in its aircraft revenues, but limited to date to development studies, especially on steam cooled concepts for AECL. They also manufacture reactor components.

AECL's official attitude is to encourage industrial participation. Regular symposia are held to inform industry of nuclear power progress and requirements, and—most important—equipment is purchased outside wherever feasible.

FIG. 3. CHALK RIVER laboratories border on Ottawa River; NRU is in large building in center, NRX is to right of it



Competitive Nuclear

Operating on natural fuel costs of less than 1 mill/kwh CANDU-type reactors will compete successfully with modern coal plant for 200-Mw(e) base-load duty on Ontario power grids

By W. B. LEWIS, *Atomic Energy of Canada Ltd., Chalk River, Ontario, Canada*

URANIUM IS a much cheaper fuel than coal, but nuclear plants are more expensive than coal-fired plants. We can expect, however, that as more nuclear plants are built, the costs will fall considerably. Already our engineers in Canada estimate for the CANDU reactor that the second and subsequent reactors of this type will be fully competitive for load factors higher than 60%.

In the industrial region of Southern Ontario the total demand for electric power is rising by more than 200 Mw(e) each year. We expect this annual demand for new generating plant to double within fifteen years. With the completion of the St. Lawrence Seaway the available water power has been almost all harnessed. The new demand for power is being met by the installation of large-capacity thermal plants, notably the 1,800 Mw(e) Lakeview Plant, near Toronto, burning coal, imported from the U. S. at $8–$9 a ton.

There is every expectation that future increases in plant capacity in Canada will be shared between nuclear and conventional thermal plants. The present price of coal sets the level at which nuclear power must compete; coal prices may rise, but if they do, oil and natural gas will come in, which together with possible improved efficiencies will hold the cost of fossil-fuel power at its present level for the next two decades.

I propose to compare, in some detail, the expected cost of power in Ontario from nuclear and conventional plants.

Fuel Costs

Consider fuel costs first. Coal at $8/ton contributes about 3 mills/kwh to the cost of conventional power. The estimate for the nuclear fuel for CANDU is 1.1 mills/kwh (see p. 60), falling almost immediately to 0.9 mill/kwh. Potentially the nuclear fuel cost could fall even lower as the scale of production increases and we learn from experience to distinguish the essential from the nonessential in our costly fabrication procedures.

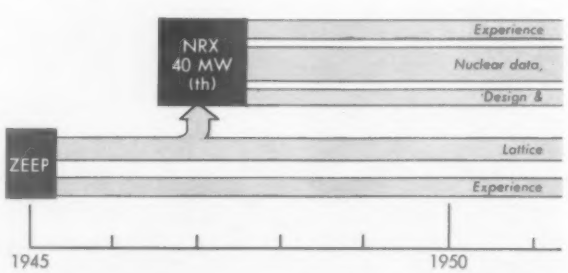
In contrast to CANDU most nuclear fuel-cycle costs (certainly for enriched fuels) involve either complex unknowns such as fuel reprocessing costs or assigned buy-back prices for the irradiated fuel. The CANDU cycle is free from such involvements; after irradiation the fuel is put in permanent storage at no credit value even though later on it may be sold for its plutonium content.

To see how far the CANDU fuel cost may fall, we note that over the next few years the price paid for uranium to the producers is expected to pass through a minimum generally accepted to be below $6/lb of U_3O_8 in mine concentrate. The CANDU type of reactor will derive about 10,000 Mwd(th) (see p. 69) from a metric tonne (1,000 kg) of uranium or 2,600 lb of U_3O_8. The CANDU plant has a net efficiency of 29.1%, so that the net electrical energy is 2,910 Mwd(e) or 70,000,000 kwh(e). The 2,600 lb of U_3O_8 will cost less than $15,600, which contributes 0.22 mill/kwh to the fuel cost. The gap between 0.22 and 0.9 mill/kwh represents the estimated cost of fabricating the fuel into suitable form and is many times the cost of the extra cladding and structural material (zirconium alloy) introduced. When fuel is standardized so that automatic fabrication becomes possible, the fueling cost could perhaps be brought down to 0.6 mill/kwh even during the lifetime of the first CANDU reactor and to less for larger reactors of the CANDU type with higher burnup and station efficiencies (see p. 60).

Effect on Capital Costs

Let us now calculate what this low fuel cost will mean in terms of allowable capital cost for a nuclear plant. The coal-fired Lakeview plant is estimated to cost about $137/kw(e), and its fuel cost will not be less than 3 mills/kwh. The operating costs for large nuclear plants are not expected to be very different from those for large coal-fired plants. (The large-scale operations of coal and ash handling are balanced by

GENEALOGY OF CANADIAN



the costs of heavy-water makeup and upgrading.) We can, therefore, assume operating costs the same; if any difference exists, one way or the other, it would be no more than 0.3 mill/kwh.

In addition to the operating cost c_o of about 0.6 mill/kwh, we can identify the following factors contributing to the total cost of power: fixed annual charges (including interest on capital), amortization, insurance and taxes on the one hand, and fueling cost c_f, on the other. The fixed charges are not all proportional to the capital investment, but it is convenient to express them as a fixed annual rate A (%) on the total capital C [in \$/kw(e)].

The total cost of power is then

$$\frac{CA}{876.6u} + c_f + c_o \text{ mills/kwh}$$

where u is the capacity (load) factor and 8,766 is the hours per year.

The difference in costs between the nuclear and conventional plants, if we assume A, u and c_o are the same, is then

$$\frac{A}{876.6u} \times \Delta(C) + \Delta(c_f) \text{ mills/kwh}$$

where Δ represents the difference of the quantity in parentheses.

We have seen $\Delta(c_f)$ gives a savings for the nuclear plant of not less than $3 - 0.9 = 2.1$ mills/kwh. In the Ontario system A is less than 7%, so for $u = 80\%$,* $A/876.6u < 0.01$. The extra allowable capital cost of the nuclear plant is at least \$210/kw(e). With the estimate of C = \$137/kw(e) for the large conventional plant the total capital cost for the nuclear plant can be \$347/kw(e). We estimate that a second CANDU would actually be built for no more than this; in subsequent plants the power may go up to 300 Mw(e) or 400 Mw(e) and the capital cost, excluding effects of inflation, would fall below \$300/kw(e) and possibly to \$265/kw(e). For C = \$300/kw(e), $A = 7\%$, $u = 0.8$, $c_f = 0.9$ and $c_o = 0.6$ mill/kw(e) the cost of power becomes 4.5 mills/kwh(e).

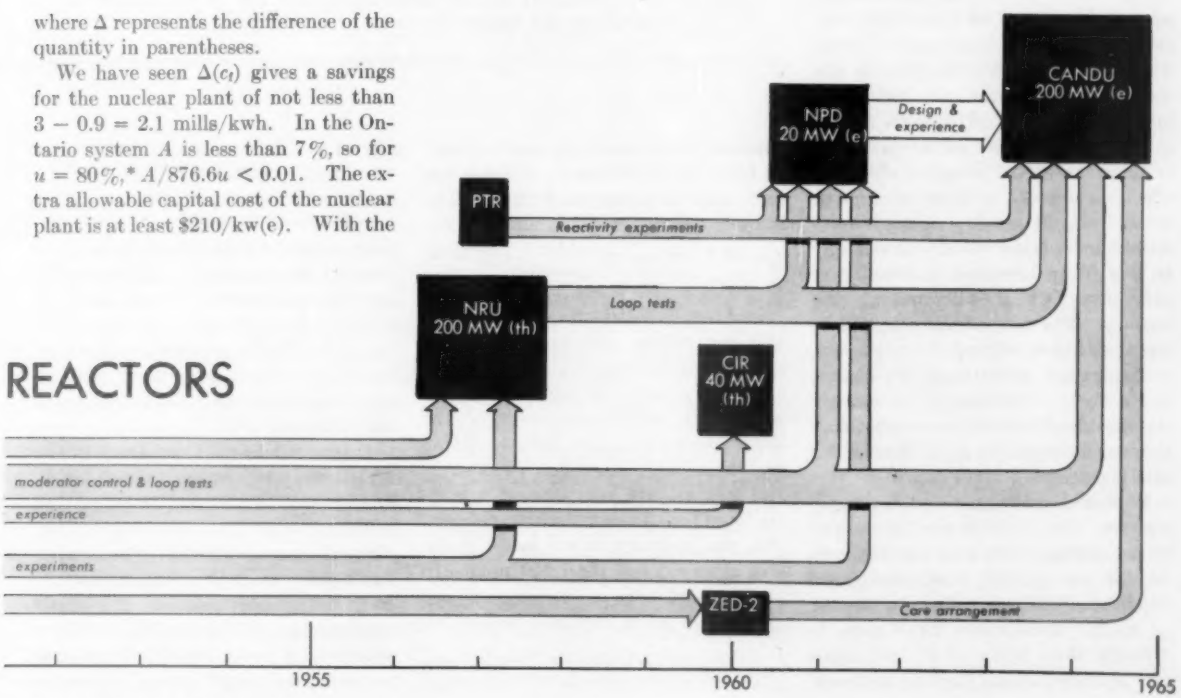
In other circumstances the rate for annual charges may be different but the corresponding costs are readily evaluated from the information given. For example, in the United States A = 14% would be more typical for a private utility; if we take this value for A and leave the other parameters unchanged, the cost of power becomes 7.5 mills/kwh(e).

* In 1958, 80% of the total kilowatthours supplied by Ontario Hydro plants was produced at a load factor of 70% or better (Annual Report Hydro Electric Power Commission of Ontario, 1958).

Bases for Cost Predictions

The preceding expectations presume no advances in technology such as the production of a new alloy, or operation at higher fuel ratings than already tested. They do, however, presume manufacturing and construction development because reactors of the CANDU type have not yet been put into operation. On the other hand the CANDU reactor is very closely similar in most important respects to the NPD-2 (Nuclear Power Demonstration) reactor that is nearing completion. The fuel channels and fuel bundles are of the same size and both reactors employ horizontal, on-power, bidirectional refueling [see p. 66 for article on refueling]. The fueling machines for NPD-2 are, therefore, full scale.

Reactivity lifetime. The prediction of the fuel burnup involves two separate



predictions, namely the initial excess reactivity and the change with burnup. The initial excess reactivity is so great that neither NPD nor CANDU can be loaded initially wholly with natural uranium. To bring the reactivity down to a reasonable level we propose not to use a burnable poison but rather to make up a small fraction of the initial loading from uranium depleted in U^{235}. The neutron capture in U^{238} in such fuel is similar in its effect on reactivity to a burnable poison but is more economical of neutrons because the plutonium thus produced remains in the reactor as added fissionable material. If the initial fuel loading in CANDU were wholly natural uranium, we calculate that the excess reactivity would be about 5% $\frac{\Delta k}{k}$—or as we commonly express this in Canada 50 milli-k—at full power. The basis for this calculation comes from measurements in the zero power reactor, ZEEP, at Chalk River. These experiments have involved actual 19-element bundles of UO_2 fuel, Zircaloy tubes, and even a hot heavy-water-cooled channel in a pressure tube to ascertain the effective neutron temperature. Similar but less elaborate experiments formed the basis for predicting the reactivity of the 200-Mw NRU research reactor commissioned in 1957 and in operation at Chalk River. For that reactor the predicted excess of 40 milli-k was realized within experimental error of about 2 milli-k. For CANDU there is one difference, namely the very high maximum temperature of the UO_2 fuel at full power; but the extrapolation to embrace this—the so-called Doppler effect—is believed accurate within 3 or 4 milli-k. Moreover, if reactivity should prove lower initially, it can only be due to an increased production of plutonium, which will prolong the burnup. The net reduction would be less than 3% in burnup.

The second prediction is the change of reactivity with burnup, on which a special study has been made over many years as discussed by A. G. Ward in his article on p. 69.

Radiation damage. Irradiations of sintered UO_2 in various forms and power ratings, with and without ruptures in the cladding, have been carried out in the NRX reactor over a number of years. Irradiations have gone to 100,000 Mwd/tonne of U (ten times our operating goal) and to temperatures beyond the melting point of UO_2, in thick and thin cans. We can say with confidence that the burnup will be limited only by reactivity and that the specified rating of $\int_{\text{sheath}}^{\text{center}} k\,d\theta = 40$ w/cm* (or 503 w/cm length of solid round rod) is satisfactory and that fission-gas release will not cause any swelling or deformation of the can.

Zircaloy clad. Zircaloy has proved adequately corrosion-resistant for the duty specified against both oxidation and hydriding. One fuel element at full temperature and pressure was irradiated for 15 months with a defected can; the hydrogen in the metal of the can averaged less than 300 ppm. In the CANDU type of reactor we do not propose to leave ruptured fuel in for any length of time, as it can be removed with the reactor at full power. If, however, an unusually serious defect developed so that a large surface of uranium oxide became directly exposed to the coolant, we would shut the reactor down to remove the element, losing, as a result, about 40 hr of operating time owing to Xe^{135}. Several such occurrences have been deliberately induced and handled in the hot-water loops in the NRX reactor.

Pressure tubes. Confidence in the Zircaloy pressure tubes rests on highly encouraging mechanical tests coupled with metallurgical understanding. Since the annealed metal hardens under irradiation, we have chosen to use 15–20% cold-worked metal. The property changes of this material are very satisfactory under irradiation at temperatures up to 380° C—well above the

* See p. 63 for explanation of fuel-rating convention.

Cost Estimates for CANDU: The Ground Rules . . .

The 1959–1960 Annual Report of AECL estimates a power cost of 6–7 mills/kwh for the first 200-Mw(e) station and 12–15% less for the 400-Mw(e) station (see Table 2). The estimates for the first 200-Mw(e) unit at the Douglas Point Station are derived on the following bases:

● Fueling Cost

Fuel cost = \$30/lb UO_2 (expected to fall to \$24/lb UO_2)
Fuel burnup = 9,750 Mwd/tonne U
Net station efficiency = 29.1%
No credit claimed for spent fuel
Hence fueling cost initially = 1.10 mills/kwh but expected to fall to 0.88 mill/kwh

● Fixed charges

Charges include interest, insurance and depreciation covered by a sinking fund for which asset lives are assigned as follows:

Reactor and fueling equipment	15 years
Other plant and half initial fuel charge	30 years
Heavy water	40 years

The insurance rate is \$1/kw per year (~0.14 mill/kwh). The reactor is designed with all parts replaceable so that its life can be extended to match the 30 year life of the remainder of the plant. Heavy water is replaced and upgraded on the operating account so it becomes a nondepreciating asset; according to utility custom for such assets it is written off in 40 years.

The interest rate, although subject to fluctuations (which will reflect themselves in the total cost of power), is expected to be in the range of 4.5–5.5%.

Combining these factors we get a total fixed charge rate of 6.5–8.0%.

● Operating cost

We estimate staff including overhead at an average of \$10,000/yr per capita. The total staff for the first plant would be 100. The Douglas Point site is laid out for two reactors with a total output to 400 Mw(e); for both reactors the staff would increase only to 110.

The total for replacement and upgrading of heavy water, other supplies and maintenance is estimated at 1.02 mill/kwh for the 200 Mw(e) station or 0.70 mill/kwh for the 400 Mw(e) station.

. . . and a Detailed Breakdown of Costs

TABLE 1—Capital-Cost Estimates for CANDU (first unit at Douglas Point)

Item	*Cost ($10⁶)*	*Running totals ($10⁶)*
Site costs, land and improvements	877	
Building, structures and shielding	5,009	
Reactor, boiler and auxiliaries	11,196	
Turbo-generator and auxiliaries	7,145	
Electrical and instrumentation	6,100	
Common processes	3,330	33,657
Construction plant and indirects	3,284	
Heavy water and helium	11,677	
Purchasing, inspection, accounts and insurance	1,561	50,179
Contingency	8,567	
Subtotal: plant and equipment (1960)		58,746
Escalation (based on 3% price increases p.a.)	4,163	
Subtotal: plant and equipment (1964)		62,909
Engineering	8,150	
Commissioning including training	1,250	
Interest during construction (at 5¾% p.a.)	9,198	81,507* = $407/kw(e)

* The Canadian practice of calculating fixed charges is to add on to this amount half of the value of the initial fuel charge which would come to an additional $2.3-million (including contingency and interest).

TABLE 2—Power-Cost Estimates for CANDU (mills/kwh)

	First unit 200 Mw(e)	*Twin unit 400 Mw(e)*	*2nd unit increment 200 Mw(e)*
Fixed charges	3.9 to 4.9	3.3 to 4.4	2.7 to 3.8
Fueling	1.1 1.1	1.1 1.1	1.1 1.1
Operating	1.0 1.0	0.7 0.7	0.4 0.4
Total	6.0 to 7.0	5.1 to 6.2	4.2 to 5.3
With fueling at 0.88 mill/kwh			
Total	5.8 to 6.8	4.9 to 5.9	4.0 to 5.1

operating range. Moreover, the strength and impact fracture properties of the metal after irradiation and containing up to 400 ppm of hydrogen (which implies hydride precipitation) have proved quite satisfactory even down to temperatures of −130° C. Nothing discouraging has appeared in our own operating experience with the pressure tubes in the NRX and NRU reactors. Tubes subjected to burst tests at operating temperatures and five times the operating pressure have split cleanly and left the rolled joints in the end fittings intact, as described on p. 96 by W. A. Wolfe. We are continuing studies of creep and stress relaxation under irradiation but so far have found nothing to cause concern.

D_2O makeup. One of the questions most often asked concerns the allowance for loss of costly heavy water. A loss per year that lies in the realistic range is 2% on the CANDU inventory of 180 tonnes, or 20 lb per day. The corresponding makeup would cost about $235,000/year, or 0.17 mill/kwh. If such a loss were encountered, as much as a $1-million capital cost might be well spent to reduce it by half. There will be some small unavoidable losses, for example in the transfer of spent fuel to its underwater storage. Even here, if necessary, savings can be made—for example, washing the fuel in 5% D_2O could reduce the loss by at least a factor of ten. The cost of upgrading the D_2O downgraded to 5% should not exceed $8/lb, so that the over-all cost of the losses would be reduced by a factor of three. Such complications are not thought necessary because the anticipated losses are acceptable. A major feature of both the NPD-2 and CANDU plant designs is a sealed-vapor barrier at atmospheric temperature and pressure to contain the D_2O expected to leak from the reactor and the circulating pumps; these leaks, hence, are not losses. Within these vapor-sealed spaces, circuits carrying normal light water are designed and constructed to strict specifications to avoid leaks that would downgrade the D_2O. The steam-generating heat exchangers, however, keep normal and heavy water separate only through the integrity of the tubes and seals. Necessarily the heavy water is at a higher pressure and the normal water is monitored to detect any slight in-leakage of D_2O. Action to repair a leak, eliminate or replace a tube or section of the heat exchanger would be taken as dictated by the over-all balance of costs and values. The heat exchanger by which the moderator is cooled presents a similar situation.

Station efficiency. The low position of heavy-water reactors in the U. S. AEC 10-year assessment is largely because of the low net station efficiencies predicted (23% by the then current U. S. technology, rising to 26%). We might point out that for CANDU the turbine contract has already been let based on a steam-cycle efficiency of 33.3%. This figure is guaranteed by the turbine manufacturers* and confirmed by consulting engineers. This leads to a net station efficiency for CANDU estimated at 29.1%. In future reactors of the CANDU type we expect these efficiencies will be still higher.

Capital-cost factors. The capital cost estimate of the CANDU reactor compares favorably with that of other heavy-water-reactor designs and appears based on sound reasons. Reactivity control by moderator level eliminates much of the cost of systems that employ control rods. We have controlled the NRX reactor in this way since May, 1958. The gas-balance system of scram control also possesses inherent safety aspects.

All large reactors are subject to xenon oscillations. The NPD-2 reactor is too small for these to be significant. The CANDU reactor may just be large enough; it falls on the borderline where predictions are not very certain. If necessary, four adjuster or flux-balancing rods of low reactivity worth and

* The contractor is Associated Electrical Industries Ltd., Manchester, England.

Summary of Data for Douglas Point Generating Station (CANDU)—Canada's First

GENERAL DATA

Reactor	
Type	Pressure-tube, pressurized-water
Fuel	Natural uranium oxide (UO_2)
Moderator	Heavy water
Coolant	Heavy water
Purpose	Base-load power generation
Owner	
Plant	Atomic Energy of Canada Ltd.
Site	Hydro Electric Power Commission of Ontario
Location	On Lake Huron near Kincardine, Ontario
Construction complete	Mid-1964
Reactor thermal power	698 Mw(th)
Generator output	220 Mw(e)
Net station output	203 Mw(e)
Over-all station efficiency	29.1%

REACTOR SYSTEM

Fuel

Form	Bundles of 19 cylindrical tubes containing sintered UO_2 pellets
Cladding	Zircaloy-4
Length of fuel bundle	19.5 in.
Number of bundles	12 in each of 306 sites (10.1 between coolant inlet and exit feeders)
Density of pellets	10.4–10.7 gm/cm³
Thickness of cladding	0.015 in. (0.030 in. for center element in each bundle)
Nominal max. sheath temperature	575° F
Nominal max. heat flux	333,000 Btu/hr/ft² (105 watts/cm²)
Nominal max. $\int k\, d\theta$	40 watts/cm (see p. 63)

Coolant Pressure-Tube Assemblies

Coolant flow	Opposite directions in adjacent tubes
Max. coolant velocity in tubes	~25.5 ft/sec
End-fitting material	Stainless steel type 410
Tube material	Zircaloy-4
Number of tubes	306
Tube wall thickness	0.157 in. nominal (tentative)
Tube inside diam.	3.25 in.
Tube length	17 ft 7 in.
Over-all assembly length	30 ft 3 in.

Calandria

Calandria shell	
Form	Horizontal cylinder
Material	Austenitic stainless steel
Internal diam	19 ft 8 in.
Inside length	16 ft 5 in.
Calandria tubes	
Material	Zircaloy-2
Thickness	0.05 in. (tentative)
Internal diam.	4.20 in. (tentative)

Core

Number of cells	306
Cell array	Approx. elliptical (20 × 19)
Lattice pitch (square)	9 in. (22.86 cm.)
Active zone fuel capacity	47.19 tonnes UO_2

Nuclear Characteristics

Max. thermal flux	10^{14} n/cm²/sec (average across hottest section)
Avg./max flux–radial	0.7885
Avg./max flux–axial	0.649
Fuel burnup (average)	9750 Mwd/tonne uranium

Fueling

Bundles replaced per operation	2 bundles, each 19.5 in. long
Operations per day	2.5 average
Refueling frequency	
In a central channel	2 bundles every 4 months
In an outside channel	2 bundles every 6 months

HEAT-TRANSPORT SYSTEM

General

Coolant	Heavy water
Quantity	94,000 lb
Total flow	2.41×10^7 lb/hr 55,800 gal (U. S.)/min

quite distinct from the control system will be applied.

Both NPD-2 and CANDU are designed to operate with a minimum excess reactivity to conserve neutrons and thus keep down the fueling cost. After any short shutdown, the xenon poison rises above the normal level. To override this when starting up the reactor, booster rods are provided. These are rods containing enriched uranium cooled by cold heavy water and, for safety, limited to slow movement. This proves far cheaper than any other means of providing the required temporary excess of reactivity.

Such are the main technical bases for our expectations. If any reader suspects that something of significance is being overlooked, we would be most anxious to hear of it.

Future Prospects

The Canadian program is committed at present only to the first 200-Mw(e) CANDU unit at Douglas Point. Our studies at Chalk River indicate no other reactor type is able to compete with the CANDU type for such situations. In other circumstances where, for example, interest and tax rates are higher, the reactor design would be optimized for a lower capital cost and higher fueling cost.

Although much of the redesign would result only from experience with the construction of the first CANDU reactor, certain potential improvements already show promise. The greater part of the neutron wastage occurs by neutron absorption in the Zircaloy pressure tubes. We already know of stronger zirconium alloys that would allow us to use thinner tube walls, but the strongest have less corrosion resistance. We are studying a composite tube of the strong alloy lined with Zircaloy-4.

The thermal insulation between the hot coolant and the cool moderator is provided in NPD-2 and CANDU by a space outside the pressure tube filled with air or CO_2. We could save reactivity if this gap could be reduced to bring the moderator closer to the fuel.

Full-Scale Nuclear Power Plant

Outlet temperature	560° F
Outlet-header pressure	1310 psi
Inlet temperature	480° F
Inlet-header pressure	1473 psi

Boiler

Number and type	8 boilers, each consisting of 10 vertical U-shell-and-tube heat exchangers and 1 steam drum
Total surface area	74,500 ft²—boiling area 11,050 ft²—preheating area
Tubes	70% Ni 30% Cu (Monel) ½ in. o.d.
Total evaporation rate	2,562,000 lb/hr
Steam pressure	583.7 psia
Steam quality	0.25% moisture
Feedwater inlet temperature	340° F (171° C)

Primary Coolant Pumps

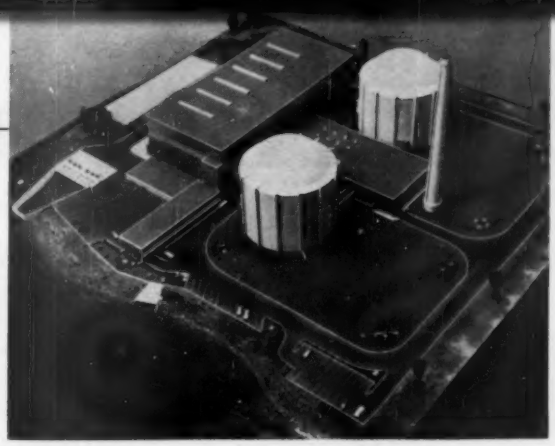
Number and type	10 (8 active) shaft-sealed, centrifug.
Arrangement	2 groups of 5 in series-parallel
Capacity (each)	7,000 gal (U. S.)/min
Operating head	200 psi

CONTROL SYSTEM

Method of Changing Reactivity	*Purpose*
Moderator level	Startup, shutdown, scram
Absorber rods	Trim
Enriched rods	Startup after short shutdown
$CdSO_4$ in moderator	Added for cold startups; removed for operation

TURBINE-GENERATOR

Number and type	One 220 MW tandem compound turbine-generator with moisture separators and reheaters. Generator is 3 phase AC with motor-driven exciter



SCALE MODEL of Douglas Point Station shows two reactor units that can be accommodated. Only one has been authorized to date

Throttle steam pressure	579.7 psia
Throttle temperature	482° F
Number of steam separators	2 in parallel
Number of reheaters	2 in parallel
Steam conditions to low-pressure cylinders	
Pressure	67.9 psia
Temperature	430° F
Condenser back pressure	1 in. Hg
Number of stages of feedheating	3 low pressure heaters 1 direct-contact deaerator 2 high-pressure heaters
Final feedwater temperature	340° F
Cycle efficiency	33.34%
Power output	220,000 kw (p.f. = 0.9)
Shaft speed	1800 rpm
Terminal voltage	18 kv
Frequency	60 cycles/sec
Phase	3
Condenser	
Type and number	1 horizontal single-pass surface condenser
Surface area	158,000 ft²

We are studying designs of thermally insulated composite pressure tubes. If these are successful we will be able to design for a combination of a flatter flux distribution and a smaller reactor vessel; both these changes reduce the mean fuel burnup but effect some saving in cost.

Still greater capital-cost savings are being sought for reactors of power lower than 200 Mw(e) by replacing the pressurized heavy-water coolant with an organic liquid [see article on the OCDR concept (organic-cooled heavy-water-moderated reactor) on p. 78]. The penalty of neutron losses to the hydrogen atoms in the organic liquid is partly offset by the reduced losses in the insulated coolant tubes. In the interest of high steam-cycle efficiency the organic liquid should operate at the highest temperature it can withstand. The insufficient experience with the materials at such operating conditions meant that development must precede the design of a power reactor. For this purpose we are studying an experimental reactor—the Organic Cooled D_2O Reactor Experiment. The OCDRE will possibly be constructed at the new Canadian atomic energy research site at Whiteshell in Manitoba.

In the long-term pattern of Canadian industrial development we can foresee that all the available water power will be harnessed and yet will contribute only a small part of the total power required. In these changing circumstances the national asset of abundant water will to a greater extent be used for power storage and reserves to meet peak power demands. No end is in sight to the demand for more power at lower cost, not only in operating and refueling cost, but also in capital cost. There is abundant coal, oil and natural gas in certain regions of the prairie provinces but elsewhere transmission or transportation costs raise the cost of power so that nuclear power will become competitive for progressively more of the load. All forecasts agree on this—they differ only on the questions of where, when and how much.

CANDU Fueling Costs—

Hardware—not hope—is behind the 1-mill/kwh cost of CANDU fuel, which benefits from development, fabrication and use of the similar NPD fuel. Both types have been tested under reactor conditions

By A. J. MOORADIAN and J. A. L. ROBERTSON, *Atomic Energy of Canada Ltd., Chalk River, Ontario, Canada*

How Barrier Will Be Broken—Economics

The fueling cost of 1 mill/kwh, or less, should be achieved for the second CANDU core charge. Significant cost reductions, relative to NPD costs, are anticipated in three areas of fuel production: (1) finished UO_2 pellets, (2) finished Zircaloy components, (3) assembly and testing of fuel bundles.

These expected cost reductions are based on two principal advantages our approach already enjoys over most American projects:

1. Natural uranium avoids the costs of enrichment accountability and criticality control.

2. The small size of the fuel bundle and components reduces the capital cost of both assembly machinery and floor space (for example, note in Fig. 4 the small size of the automatic wire-wrap welding machine). With regard to floor space, only 4,500 ft² are required to take ceramic-grade powder to finished fuel bundle (cf. 20,000 ft² for NRU fuel with a core length of 10 ft).

Expected Reduction in Fueling Costs

	Fabrication costs ($/lb UO_2)	
Steps in process	*NPD costs*	*1964 (expected)*
Finished UO_2 pellets		
Yellow cake	9.00	6.00
Yellow cake to powder	3.00	1.50
Sintering, grinding	4.00	3.00
Total pellet cost	16.00	10.50
Zircaloy components	12.50	7.50
Assembly, inspection	9.00	9.00
Total fabrication cost	37.50	27.00

Finished UO_2 Pellets

Finished NPD fuel pellets are made today for about \$16/lb UO_2. Three components make up this figure: yellow cake, yellow cake to ceramic-grade powder, and sintering and grinding.

Yellow cake can be expected to fall to \$6/lb (*40*). The \$3/lb for conversion of yellow cake to ceramic-grade powder reflects the disadvantage of small-scale batch operation. There is no inherent reason why continuous production at a reasonable level should not yield \$1.50/lb or less. Development work is now in progress at Eldorado Mining and Refining to exploit this possibility. The \$4/lb for sintering and grinding has been achieved without complete mechanization. With future expanded production, a more realistic figure would be \$3/lb or less.

Thus, it is reasonable to expect that finished pellets will be produced for \$10.50/lb or less, probably before the second CANDU charge.

Zircaloy Components

Finished Zircaloy components, ready for assembly, cost about \$12.50/lb UO_2 for NPD.

The largest contribution is cost of tubing. Significant inroads in this cost can be expected from improvements in the conventional process or by developing new techniques, such as impact-extrusions, which are uniquely applicable to short-length tubes. The latter employs fewer operations but allows the incorporation of integral end plugs and yields a homogeneous fine-grain structure suitable for ultrasonic inspection. Already, under AECL contract, Thompson Products Ltd., St. Catherines, Ontario, has shown the feasibility of impact-extrusion and is developing it for the sizes required for CANDU.

The present NPD-element end plugs are precision-machined from bar stock. Forged or stamped end plugs will significantly cut the production cost.

End plates are now stamped and machined from sheet so that the holes cost more than the residual plate. Several end-plate designs are being considered to cut Zircaloy waste.

An analysis of the developments mentioned leads to the expectation that Zircaloy-component costs can be reduced to \$7.50/lb UO_2 within the next two or three years. Even at this figure, finished Zircaloy costs over \$80/lb, a factor of 10 over the ingot cost. Obviously, the incentive for continuing cost reductions will exist for some time.

Assembly and Inspection

Assembly and inspection costs for NPD are already about \$9/lb UO_2, largely because of the short length and large diameter of the fuel elements. Applying this as an upper limit to CANDU yields a total cost of under \$27.20/lb UO_2, i.e., the immediate goal of 1 mill/kwh. More development dollars, however, are being spent in this area than in the other two combined, and further economies are expected through automation of inspection equipment, development of resistance closure welds, possible elimination of autoclave corrosion tests, redesign of the end fitting for easy assembly, etc.

Breaking the 1-Mill/kwh Barrier

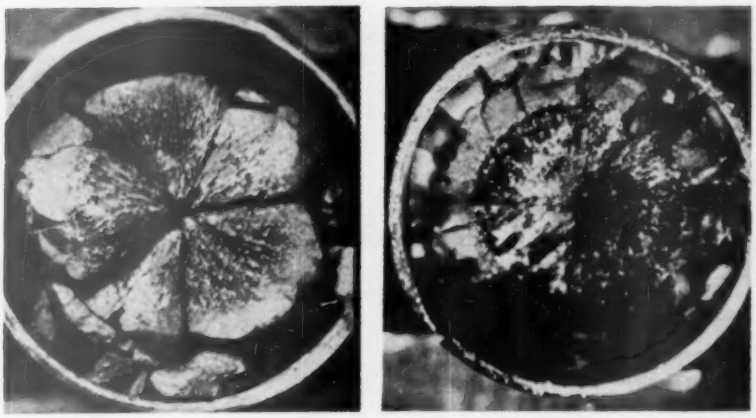
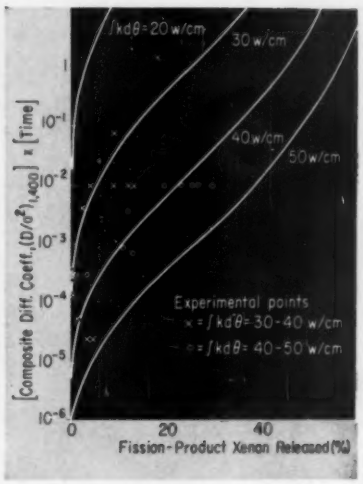


FIG. 1. IRRADIATED UO_2 cross sections: at left, without central melting (NRX X-2 loop, 0.75-in. UO_2 diameter); at right, with central melting (NRX "hydraulic rabbit," 0.66-in. UO_2 diameter)



How Barrier Will Be Broken—Technology

FOR MANY YEARS fueling costs of under 1 mill/kwh have been a realistic goal to some but a mirage to others. Now production experience with fuel for Canada's Nuclear Power Demonstration reactor and extensive irradiation testing show why they should be taken seriously. (Present and projected costs are presented on page 60.)

The fuel bundles for our first full-scale power reactor, CANDU (see box, p. 62) will be similar to those of NPD and will thereby profit from NPD fabrication and operating experience. The interim development between NPD and CANDU has been mainly confined to increasing heat output while decreasing the parasitic content of the fuel assembly by improved fabrication. Current investigations are aimed at completing the design of the first charge for CANDU by June, 1962.

Selection of Fuel Design

Because the reasons for choosing Zircaloy-sheathed stoichiometric-UO_2 fuel elements have been discussed previously (*1–6*), we shall consider here the basis for selecting the design.

A cylindrical-rod geometry was selected because of its simplicity for fabrication and inherent stability and because of more extensive practical experience with this form. Although flat plates and annular elements containing unbonded UO_2 offer the potential advantage of decreasing the sheath/fuel ratio, they are more susceptible to failure by water-logging (*7*). The relatively short length of the element bundle suits progressive fueling needs (*8*).

The original choice of materials and geometry was largely based on information obtained by Westinghouse's Bettis Laboratory, who had irradiated specimens in reactor loops at Chalk River. Since then, experimental work has been aimed at investigating potential limitations in the fuel-element design to obtain a fundamental understanding of the physical processes involved. Ideally, the fuel should operate at the maximum value of $\int kd\theta$ (see box, p. 63) consistent with a low sheath/fuel ratio and an acceptably low rate of failure. That metallurgical effects of burnup do not limit our use of natural UO_2 has been shown by Bettis irradiations in NRX to >50,000 Mwd/tonne U (*10*).

UO_2 melting. Specimens irradiated in pressurized water at a heat rating of $\int kd\theta$ = 40–50 watts/cm developed a columnar grain structure and central void in the UO_2 (Fig. 1). Although there were reasons for supposing that the changes had occurred without the UO_2 melting, there was concern over the possibility of operating fuel elements with molten cores.

To settle the point, specimens were irradiated for short durations to suppress the diffusion-controlled grain

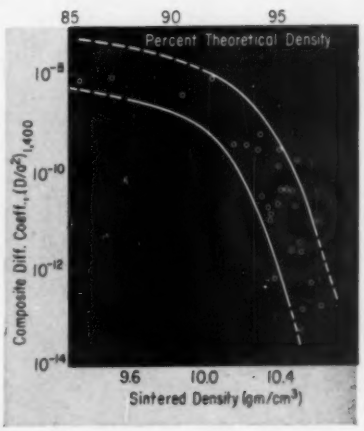


FIG. 2. FISSION-GAS RELEASE from high-density, sintered UO_2 (composite diffusion coefficient is in units of sec^{-1})

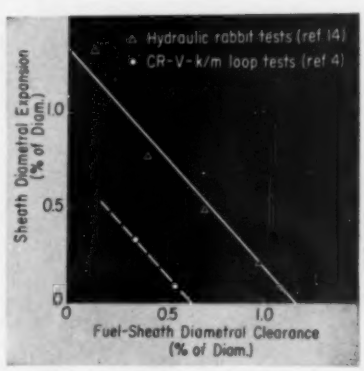

Hydraulic rabbit tests (ref 14)
CR-V-k/m loop tests (ref 4)
Sheath Diametral Expansion (% of Diam.)
Fuel-Sheath Diametral Clearance (% of Diam.)

FIG. 3. DIAMETRAL EXPANSION of sheath depends, approximately linearly, on initial fuel-sheath clearance

CANDU Fuel Data

Fuel core	Sintered UO_2 pellets; one end dished for distributed axial clearance; 10.4–10.7 gm/cm³ density; 2–2.02 O/U ratio
Cladding	Zircaloy-4*; nominally 0.015 in.
Bundles	19½ in. long; 19 elements/bundle; 0.050 ± 0.002 in. spacing between elements; 12 bundles per channel; reference design contains 11.29 in³ Zircaloy-4, 89.6 in³ UO_2; max. diameter 3.210 in. (gives minimum cold diam. clearance of 0.040 in. with pressure tube)
Elements	0.600 in. o.d.

Operating Conditions:

Coolant	D_2O	Max. mass flow/channel	10^5 lb/hr
Max. pressure on fuel	1,444 psi	Max. sheath temp.	575° F
Pressure drop across full channel (i.e., 10.1 bundles)	105.8 psi	Max. heat rating ($\int kd\theta$)	40 w/cm
		Max. kw/cm length of bundle	8.712
Inlet temp.	480° F	Average burnup	9.750 Mwd/tonne U
Outlet temp.	560° F		
Max. axial compressive load on bundle		Avg. fuel life in reactor	2.3 yr
		Max. fuel life in reactor	3.7 yr
Hydraulic	800 lb		
Friction on movement	400 lb		

* Zircaloy-4 (Zr, 1.5 w/o Sn, 0.1 Fe, 0.1 Cr) has been selected over Zircaloy-2 (Zr, 1.5 Sn, 0.1 Fe, 0.1 Cr, 0.05 Ni) because of a lower hydrogen pickup (*25*) without loss of mechanical properties; the relevant information has been reviewed by Perryman (*26*).

growth (*11*). In these, unambiguous melting occurred (Fig. 1), but only at high heat ratings. Allowing for the difference in coolant temperatures, these experiments would predict melting at $\int kd\theta = 75$ watts/cm in pressurized water. Thus a heat rating of $\int kd\theta = 40$ watts/cm provides an adequate margin to avoid melting.

Recently, Lawson and MacEwan (*12*) showed how the void and columnar grains (Fig. 1) occur without melting. Apparently, plate-like pores, perpendicular to the radius, migrate up the thermal gradient by sublimation, the polycrystalline matrix being digested and a single crystal being deposited. Since the pores end up at the center, the axial void is the consequence.

Fission-product release. Another possible limitation lies in the internal pressure caused by fission gases.

An oversimplified analysis (*4*) shows that the most important factors affecting the release are heat rating and surface temperature of the fuel, the activation energy for diffusion of the gases in the UO_2 lattice and the product of the duration of the irradiation and a characteristic parameter of the sinter.

The general form of the dependence, shown in Fig. 2, is supported by measurements of free gas in the sheaths of irradiated test elements. The top curves of Fig. 2 show the dependence of fission-gas release on heat rating and the product of [composite diffusion coefficient] × [duration of irradiation] for cylindrical specimens with a 400° C surface temperature; experimental results are compared with the predictions of the simple theory.

The characteristic parameter, $(D/a^2)_{1,400}$, has been determined in auxiliary experiments (*13*). The parameter varies with density (Fig. 2) for UO_2 prepared by a particular route. Application of these results to an element containing UO_2 of density 10.5 gm/cm³ (typical of that expected for CANDU) operating at $\int kd\theta = 40$ watts/cm for two years shows that only a 5% gas release would be expected—arising almost entirely from the central third of the fuel cross section; the remaining two-thirds would retain essentially all its gas.

Thinner cladding. The fuel-element diameter corresponding to $\int kd\theta = 40$ watts/cm in CANDU is 0.6 in. To ensure stability of an empty tube against collapse due to external coolant pressure would require 0.025-in.-thick Zircaloy. Therefore, to decrease the sheath/fuel ratio, the consequences of using a thin (0.015-in.) sheath, which relied on support from the fuel, were investigated.

It was found (*4*) that if the diametral and axial clearances between the fuel and sheath on assembly were less than certain critical values (dependent on sheath properties and coolant conditions), permanent sheath deformation was avoided. However, irradiation tests showed that thermal expansion of the fuel in specimens with small clearances could lead to permanent distension of the sheath. To a first approximation, the sum of the diametral clearance and expansion were constant for

Some Irradiations of Zircaloy-Clad UO_2 in Pressurized Water

Test designation	*Sheath* O.D. (in.)	*Sheath* Thickness (in.)	*Max. heat ratings* $\int kd\theta$ (w/cm)	*Max. heat ratings* Mwd/tonne U	*Remarks*
U-9	0.6	0.015	45	670*	19-element CANDU design
	0.6	0.015	22	500*	19-element NPD design
	1.0	0.025	30	300*	7-element NPD design
CR-V-e	0.5	0.028	40	7,000	7-element
CR-V-n/o	1.0	0.023	43	5,000*	3-element, >100 ppm H in sheath before irradiation
X-2-t	0.8	0.016	48	5,000*	
X-2-q	0.8	0.024	48	300	Sheath defected for 16 days; no change in appearance
X-2-s	0.8	0.024	46	1,000	Sheath defected for 14 days; ¼-in.-diam hole
X-1-l†	0.4	0.021	24	15,000	Sheath defected for 300 days; no change in appearance
X-3-l†	0.07-thick plates	0.015	5	75,000	No change apparent until swelling began at 55,000 Mwd/tonne U

* At August 1, 1960; irradiations continuing.
† Bettis irradiations in NRX; see refs. *10* and *15*.

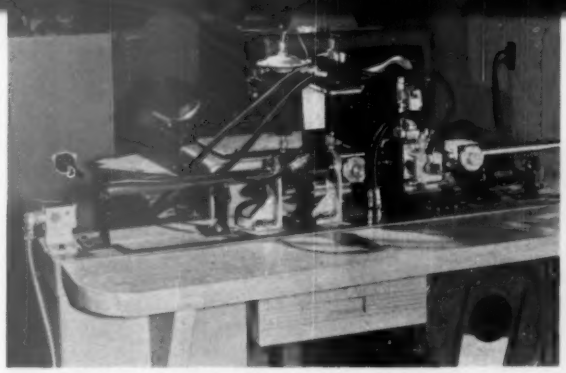


FIG. 4. HIGH PRODUCTION RATE of compact, automatic equipment, such as wire-wrap welding machine at left, has enabled CGE to rapidly build up NPD fuel-element stockpile (stack shown at right is at CGE, Peterborough)

a given heat rating. Figure 3 shows that diametral expansion of the sheath depends approximately linearly on the initial fuel-sheath clearance. Other parameters, such as coolant pressure and temperature, sheath strength and fuel heat rating, alter the position but not the slope of the lines. In Fig. 3, solid circles represent averages of measurements on three similar specimens in a pressurized-water loop ($\int kd\theta = 45$ w/cm); the triangles are for a typical group of four similar specimens irradiated in cold water ($\int kd\theta = 82$ w/cm).

For CANDU conditions, within a small range of diametral clearances, neither collapse nor distension occurred for heat ratings up to 40 watts/cm. The use of large axial clearances that could allow sheath collapse was circumvented by dishing one end face of each UO_2 pellet.

Corrosion effects. Before confirming the use of 0.015-in.-thick Zircaloy, the effects of corrosion were examined. The loss of metal thickness is insignificant ($<2 \times 10^{-5}$ in./yr), but the rate of hydriding is appreciable.

Hydrogen analyses of Zircaloy sheaths irradiated in pressurized-water loops (*15–17*) indicate that the elements can operate 1½ yr before the hydride content exceeds solid solubility. Experimentally, loop specimens whose sheaths contained >100 ppm hydrogen (the solubility limit at test temperature) have operated at $\int kd\theta = 43$ watts/cm for 15 months without incident.

Tests (*18*) have shown that "deuteriding" in heavy water is less severe than hydriding in light water, from which most of the experience has been obtained. Certainly the hydriding is more rapid in elements where the sheath has been defected, i.e., where the inner, hotter surface is also susceptible to corrosion. However, such elements have operated at $\int kd\theta = 25$ watts/cm for over a year (*15*) and at >45 watts/cm for two weeks (*19–21*) without visible effects or changes in sheath dimensions. In over 25 defect tests made at Chalk River under pressurized-water conditions, all specimens remained in one piece and none failed in a way that would prevent removal on power as required by CANDU.

The outline specifications for the fuel elements in NPD and CANDU are a direct product of these investigations. Confidence in the fuel design stems from many irradiation tests (*1, 2, 4*), culminating in recent proof tests of full-size prototype bundles under maximum rating conditions. Some of the more significant irradiations are listed in the table on p. 62.

NPD Fuel Fabrication

The translation of the NPD fuel concept into economical hardware required careful fabrication development, in which the Canadian General Electric Company has played a major part.

UO_2 pellet production. The production of pellets (*22*) was developed to a practical point through the close cooperation of Eldorado Mining and Refining Ltd., Carboloy Division of Canadian General Electric Co. (CGE), the Mines Branch of the Dept. of Mines and Technical Surveys and AECL.

Today, densities of 10.5–10.7 gm/cm³ can be achieved routinely at a reject rate of <6%, from UO_2 powder to finished sintered pellets ground to ±0.0005-in. tolerance. The high dimensional tolerances are achieved at a negligible cost because of the inherent precision of the grinding operation and the low cost of natural-uranium waste.

Helical ribs. Although all the elements of an NPD bundle are of identical size, about half require a two-start helix of 18¼-in. pitch, standing 0.050 in. above the tube. These helical spacers also circulate the coolant transversely through the bundle.

(*Continued on page 64*)

Heat Rating $= \int kd\theta$

Most of the properties that limit fuel performance are temperature-dependent, but it is rarely possible to measure fuel temperatures directly. However, solution of the heat-flow equation for a cylindrical fuel element yields

$$\int_{T_s}^{T_0} kd\theta = \frac{1}{4\pi} qF = \tfrac{1}{8} waF = \tfrac{1}{4} ha^2F$$

where k = thermal conductivity of fuel at temperature θ; T_s, T_0 = fuel-surface and center temperatures; q = power generated per unit fuel length; w = surface power flux; h = power per unit volume averaged over cross section; a = fuel radius; F = correction factor that is available in graphical form (9)—unity if there is no neutron-flux depression over the cross section; significantly less only for highly enriched fuel.

Thus $\int kd\theta$ can be evaluated from an experimentally measured heat rating with no knowledge of or assumptions regarding k. For a given fuel and T_s constant (broadly true of sintered UO_2 elements with small diametral clearances), $\int kd\theta$ defines the maximum fuel temperature on an empirical scale and is thus the best parameter for comparing the severity of irradiation in elements of different sizes. Application of the integral is discussed more fully in reference 9.

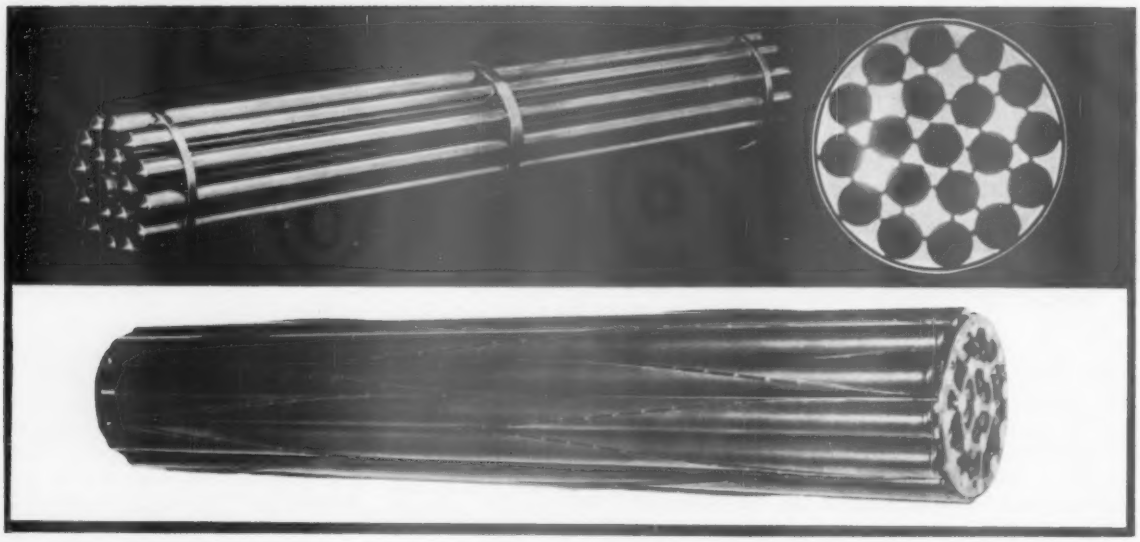


FIG. 5. TYPE OF FUEL BUNDLE without end plates, under development for CANDU, is shown at top with cross section; at bottom is NPD 19-element bundle. Features of developmental type are (1) axial thrust carried by center element alone; (2) all elements supported at midplane; (3) belly bands for sliding and spacing from pressure tube

Such helically ribbed tubes presented a worrisome production problem. Although fabricators have produced helically ribbed tubes, none has yet developed an economic process for such a high ratio of rib height to wall thickness. This problem was solved with the "wire-wrap welding process" developed by CGE—a 0.050-in.-diameter wire is stitched to the tube by spot welds at ¼-in. intervals. Tests of these ribbed tubes have indicated uniformity of weld penetration, corrosion resistance and no adverse irradiation behavior.

Zircaloy tubing. Procurement of tubing proved to be a problem. Largely because of the demanding American programs, manufacturers could routinely produce corrosion-resistant material to tight dimensional tolerances. There remained, however, the question of mechanical defects.

Some tubing had small cracks that had escaped detection by standard eddy-current inspection but were found by metallography. More recently, thin tubing has been successfully inspected at CGE by ultrasonic methods, which are capable of detecting 0.0005-in.-deep flaws, provided the background is reduced by using homogeneous, fine-grained material. It has required the close collaboration of metallurgists and tube producers to assure a supply of defect-free tubing for NPD. With the development of ultrasonic inspection for routine quality control, tubing quality and yield will be improved.

Welding and assembly. Development of the closure welds only required applying a mechanized production process to existing Zircaloy-welding methods (*23*). This procedure has met with no serious difficulty with the thin Zircaloy cladding. The automatic machines for wire-wrap welding (Fig. 4) and for closure welding are inexpensive. The secret of successful welding lies largely in the use of localized good atmospheres, cleanliness and reproducible control of welding parameters.

The elements have been assembled into bundles with either riveted or welded joints. These behaved satisfactorily under reactor conditions. However, the welded joint is stronger and meets bundle tolerances more easily on a production basis; the riveted assembly requires accurate spacing of the rivet holes in the end plate.

Corrosion and wear. Zircaloy is susceptible to fretting corrosion and penetration can be very fast [~0.002 in./day has been observed under laboratory conditions (*24*)]. The individual elements of the bundle, however, being short and massive, would vibrate with a very small amplitude. Similarly, the pressure-tube and fuel bundles should not interact seriously.

Since a complete theoretical analysis of vibrations in such a complex system is difficult and uncertain, an endurance test of a bundle abutting a supported end plate was set up in a coolant tube. After 5 months under reactor temperature and maximum-flow conditions, no fretting corrosion has been observed, either at bundle junction or between the bundle and the pressure tube. In addition, none of the irradiation tests has suggested that the elements are susceptible to fretting corrosion. Since fretting corrosion occurs rapidly, if at all, observations indicate that the design prevents fretting.

As a fuel bundle is pushed through the reactor, some wear is expected between the wire wrap and the pressure tube. Under appropriate coolant conditions, an autoclaved fuel bundle has been shuffled back and forth for a total of 200 ft in a 2-ft section of an autoclaved pressure tube. Although the wire wrap wore to the extent of 0.019 in., the maximum depth of score in the pressure tube was only 0.001 in. A round wire obviously gives a high bearing pressure at the point of contact (~50,000 psi). A program is underway to reduce this type of wear by improving the surface of the spacer wire as well as by reducing bearing pressure.

Since element bowing in a bundle could cause excessive friction at the interface between the wire wrap and the pressure tube, the five full-sized bundles in the U-9 test (see table on p. 62) were moved along the tube while

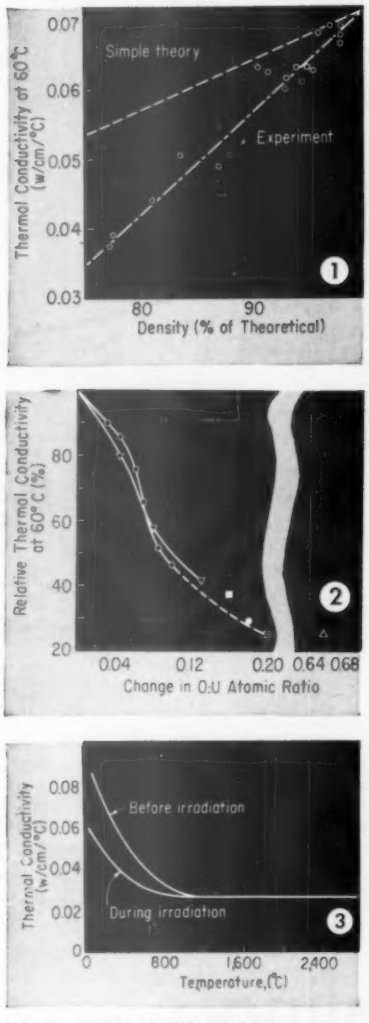


FIG. 6. THERMAL CONDUCTIVITY of sintered UO_2 is affected by (1) departure from theoretical density, (2) O:U atomic ratio, (3) irradiation. (1) and (2) according to ref. 28; preirradiation data of (3) from refs. 29–31 and during-irradiation data from refs. 4 and 32

at power. Within the experimental error of 25 lb, the thrust required was identical to the off-power requirements. This indicates that if the elements do bow, they exert negligible pressure on the coolant tube.

CANDU Fuel Development

The essential difference between the 19-element fuel in NPD and that in CANDU is the maximum rating (3.9 kw/cm length of bundle for NPD vs 8.7 kw/cm for CANDU). This difference has its greatest effect on hydraulic and structural design features.

Two concepts are being developed: The first involves upgrading the NPD 19-element bundle to CANDU requirements; the second uses the center element as the supporting member of the bundle, rather than holding the bundle together with end plates as in NPD.

Up-graded NPD design. This design is being developed in cooperation with CGE.

CANDU specifications allow a pressure drop of 105 psi over the fuel channel. The present NPD 19-element bundle gives a 72-psi pressure drop under CANDU flow conditions. Thus, 33 psi remain to improve mixing. Present studies, therefore, are directed toward this improvement by optimizing wire-wrap pitch and disposition and end-plate design.

The NPD design carries a Zircaloy inventory of 13.28 $in.^3$ per bundle, of which 3.35 $in.^3$ is associated with end plugs, wire wrap and end plates. Each cubic inch of Zircaloy per bundle which can be replaced by UO_2 is worth about 120 Mwd/tonne U-burnup in CANDU. A second design objective, therefore, involves reducing this inventory. Preliminary structural tests indicate that a cubic inch can be pared from the design without too much difficulty, most of it from the end plugs and end plates.

The differential axial expansion of the inner and outer elements of a bundle has required consideration. Although dishing one end of each pellet eliminates permanent elongation of the element's sheath, expansion in the elastic range must be expected. This is because the outer diameter of the fuel pellets is at a higher temperature than the sheath, while the coefficient of thermal expansion of UO_2 is about twice that of Zircaloy. Because there is a small neutron-flux gradient across the bundle, the outer elements will be subject to greater expansion. The consequent stresses on the end plates and plate-to-element joints are being accommodated by flexible end plates; fatigue tests on such plates, in a hydrided condition, are underway.

A second consequence of differential expansion is that the axial load will not be transmitted equally throughout all elements. However, tests have shown that a single element can withstand an axial load of 600 lb without buckling. Thus the design load of 1,200 lb, which the bundle must be capable of transmitting, can be carried by two elements.

Center-element-supported bundle. This design is being developed in cooperation with AMF Atomics (Canada).

The center element is made strong enough to carry the full axial load, requiring a sheath thickness of 0.030 in. on the load-carrying element only. The center element extends 0.050 in. longer at each end of the bundle to assure that it alone carries the full axial load. The remaining 18 elements are attached to the center element at or about the axial center of the bundle. The ends of the elements are spaced by pads, allowing free relative longitudinal movement (Fig. 5, top, is such a design).

Several advantages in this approach are immediately obvious. The differential elongation of the elements does not stress the structural support of the bundle. As a result, no concentroted axial gap need be left in loading the elements. The concept also allows a reduction in Zircaloy inventory. A bundle can be designed with about 11.5 $in.^3$ of Zircaloy.

The chief disadvantage of this approach is lack of previous fabrication experience. However, work at AMF has led to several notable achievements:

1. Domed end caps can be stamped from 0.025-in.-thick sheet in a single warm-forming operation.

2. Domed end caps (0.025 in. thick) can be resistance-butt-welded to 0.015-in.-thick tubes to give high-integrity closures.

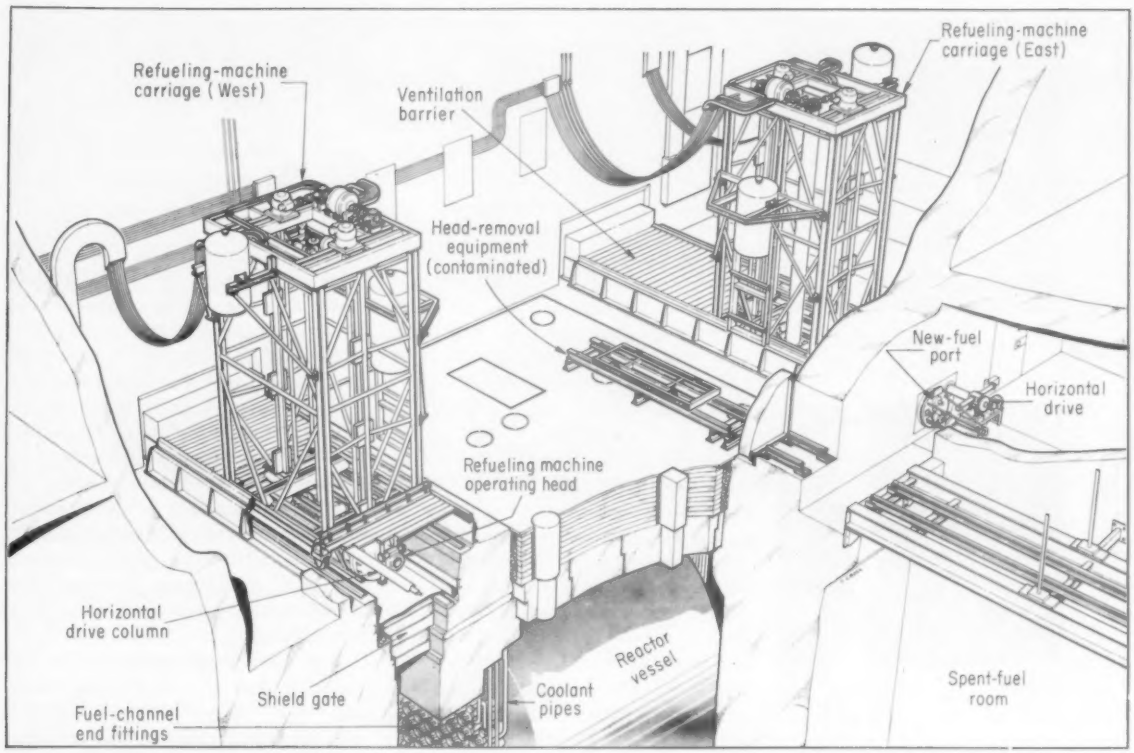
3. Spacer pads can be pressure-resistance-welded to 0.015-in. cladding to give joints as strong as the parent material.

Brazing is being extensively explored as a possible fabrication approach. Attention is being confined to the Zr-5% Be brazing alloy as a result of Schwartzbart's investigation (*27*). Under separate contract, Canadian Westinghouse has shown that, provided care is taken with the brazing cycle and atmosphere, this material has adequate corrosion resistance under static autoclave conditions. Fuel elements incorporating welded and brazed domed end caps and spacer joints have been irradiated but not yet fully examined. The joint itself retains resilience through deflection of the thin cladding despite the brittle nature of the braze.

Fundamental Studies

The foregoing program is largely empirical testing of a fixed design. Concurrently we are investigating the

(*Continued on page 122*)



1 **CARRIAGES FOR NPD's TWO REFUELING MACHINES are in room outside reactor primary shield, but small working head on each penetrates shield at opposite ends of reactor to move bundles. H_2O reflector-shield inside reactor vessel lessens radiation exposure of heads, which are inside shield only 1–2 hr daily. For typical refueling, operator drives up to five fresh fuel bundles through new-fuel port and into head of East machine. After he checks ventilation control and personnel safety, operator slides gates open and lowers heads through two slots in floor . . .**

On-Power Refueling

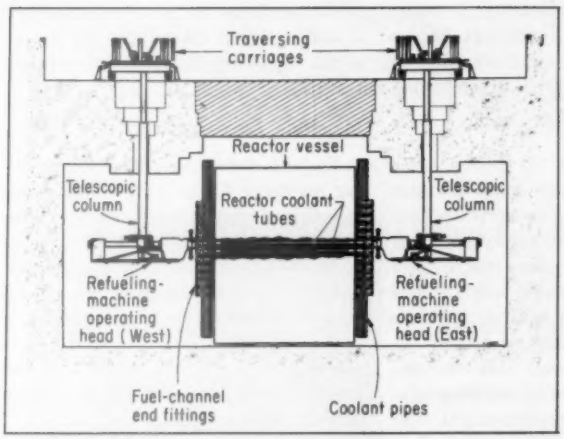
Refueling at power leads to higher, more uniform burnup and makes a reactor available more of the time. Here are the refueling scheme and machines being developed for NPD and CANDU

By J. S. FOSTER, *Atomic Energy of Canada Ltd., Toronto, Ontario, Canada*
W. M. BROWN and H. E. TILBE, *Canadian General Electric Co. Ltd., Peterborough, Ontario, Canada*

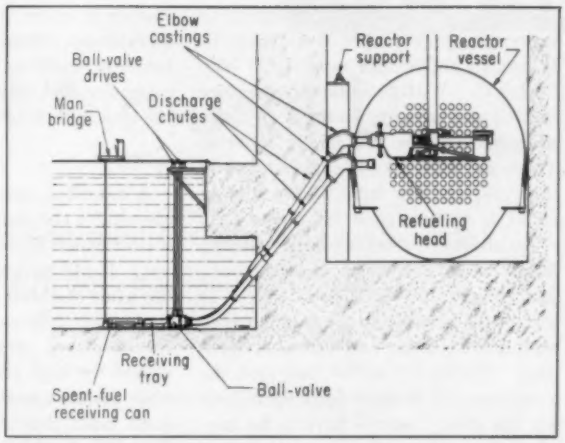
THE ABILITY to refuel a reactor while it continues to operate has been of greatest interest for natural-uranium reactors, which require frequent refueling because of their intrinsically low reactivity. But on-power refueling offers many advantages that give it value for enriched reactors too. The NPD and CANDU reactors will make use of on-power refueling; our experience can help other reactor designers to evaluate on-power refueling for their plants.

Advantages

While being able to keep a reactor operating steadily is a major product of on-power refueling, the ability to reach greater uniform burnup is even more important economically for most reactors—particularly in those with enough reactivity to support relatively long fuel cycles. With a long fuel cycle, a reactor with fixed fuel wastefully dissipates the fresh fuel's initial reactivity in poison and control materials. But if the operator can continually adjust the fuel composition throughout the



2 **OPERATOR LOCKS HEADS** onto opposite ends of reactor's horizontal pressurized fuel-coolant channel to form pressure-tight seals. After filling and pressurizing heads with D_2O, operator removes plugs from channel and stores them in heads. Then East head rams new fuel bundle into channel; this pushes all 9 bundles in channel along until spent bundle at far end contacts grappling device in West head, which then retracts spent bundle into its magazine. East head withdraws its ram and both replace end plugs . . .



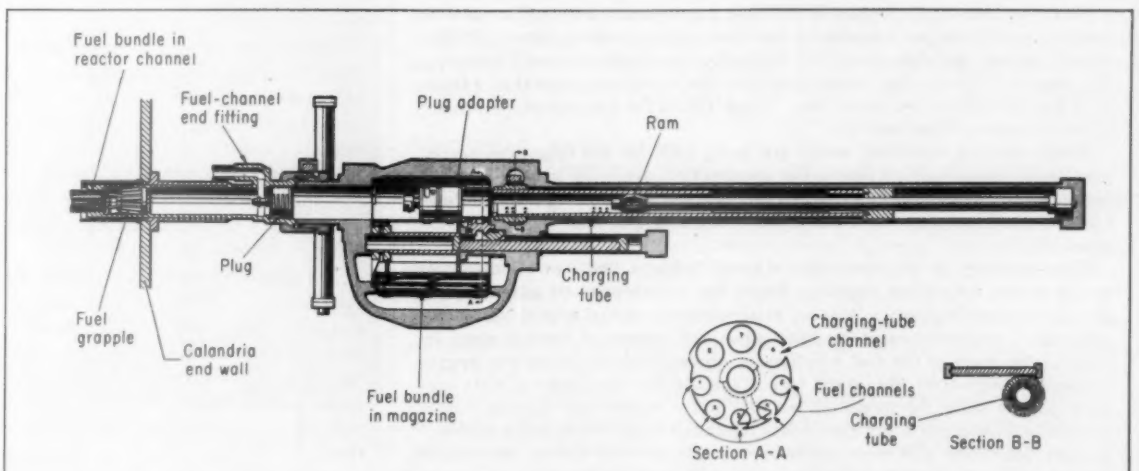
3 **AFTER MACHINES REFUEL OTHER CHANNELS** (normally only 1 or 2 bundles are changed daily), heads rotate, move to chutes and discharge spent-fuel bundles to underwater storage. To complete cycle, operator raises both heads above shield and closes gates. So as to be able to move fuel in opposite directions in adjacent reactor fuel channels, each machine can either charge or discharge fuel. All refueling steps are controlled remotely by operator in control room; sequences within steps are fully automatic

reactor so as to keep intrinsic reactivity, flux and power patterns constant as burnup, conversion and fission-product buildup proceed, the excess reactivity of fresh fuel supports the less reactive old fuel and so extends its life.

On-power refueling reduces the number of startups and shutdowns with their attendant difficulties such as thermal cycling of the reactor system. It also provides means for eliminating faulty fuel as soon as it is identified (and sometimes can aid in the identification). This reduces contamination of the reactor system and might permit some relaxation of fuel quality requirements—thus cutting current high inspection costs. Also, by distributing an operation that is otherwise concentrated in the busy plant-shutdown period, on-power fuel changing ought to produce some economy in plant staff. Fully automatic operation under the direction of a computer reacting to fuel history, reactivity and channel power data would be a logical development from present designs.

CANDU Refueling

The heavy-water reactors being developed in the Canadian nuclear power program are sufficiently reactive that on-power refueling is not essential to reasonably economic operation. For instance, with on-power refueling the CANDU reactor for the 200-Mwe



4 **EACH OPERATING HEAD**, which can hold D_2O at 1,200 psig and 530° F of reactor, can either charge or discharge fuel bundles. Magazine can hold five 19½-in. × 3¼-in.-dia fuel bundles and a spare channel plug as well as the plug removed during refueling steps. External parts of head move pneumatically and electromechanically; magnetic signals through pressure housings indicate and control position of internals, which drive hydraulically with D_2O

Douglas Point Station is designed to support burnup of 9,750 Mwd/tonne U. It has an active fuel capacity of 41.6 tonnes U. With a station net efficiency of 29% at a capacity factor of 80% the average fuel life will be 24 months. There are about 3,000 fuel bundles in the core, and the intent is to replace about 5 of them each full-power day.

An alternative to on-power refueling might be to shut down once a month and change 150 bundles at once. It should be possible to do this between midnight Saturday and 8:00 a.m. Monday. For the 4% of the time that the station would be shut down for refueling the energy would have to be supplied from alternative fuels that cost three times as much as nuclear fuels. In addition bulk refueling would reduce attainable burnup by about 4%. These penalties would result in a total increase in energy cost equal to 12% of the reactor fueling cost, or only about 2½% of the total energy cost.

Thus it is not economic *necessity* that has led to the adoption of on-power fueling in the Canadian program. Rather it is the combination of many advantages, none of sufficient importance in itself to compel adoption of on-power fuel changing, which makes the system attractive.

Cost

A refueling machine must perform essentially the same functions whether it is intended for on-power operation or not. It will have the same controls and the same shielding requirements. The important difference is that machines for on-power operation must be designed for high pressure and temperature. After a number of machines have been built this difference might cost $100,000–$300,000 per reactor for better materials, seals and special designs to cope with pressure and transient temperature conditions. The additional operating and maintenance cost is more difficult to estimate. Failures certainly will be considerably more expensive.

As with any complex mechanism on-power fuel-changing systems entail considerable development. Development of the machines for NPD and CANDU is costing about $2-million, but not all of this can be attributed to the on-power feature.

Machine Development for NPD

To help develop satisfactory refueling machines for prolonged operation, as well as tools and methods for maintenance and decontamination, we have built two prototypes that demonstrate operation and uncover problems. Also, we are conducting parallel programs to develop such things as the seal between the refueling machine and the end fitting and to learn about performance of various components.

First prototype and results. From March to December, 1959, we operated the first machine and test rig, which includes several simulated reactor fuel channels with NPD-2 water flow, temperature and pressure. This experience indicated that (a) the mechanical design and control concept are fundamentally sound, (b) a Viton-A (fluorine elastomer) O-ring seal between head and fitting was suitable only for a limited number (less than six) of make-break cycles, (c) water lubrication of hydraulically operated internal parts was satisfactory even after about 300 cycles. But we found that off-the-shelf items do not meet our needs for reliability, leaktightness (valves) and lack of hysteresis. Also, we learned of the excessive stresses in the magazine housing and the need for cooling the head; we are seeking solutions to these two problems in the present experimental program.

Second prototype and experiments. After stripping and examining the first prototype we have rebuilt it with modified carriage, controls and hydraulic circuitry and new head and suspension. Since May we have been checking its performance. By year end we hope to verify that this design meets our design specifications.

Our parallel search for solutions to the thermal problems of the refueling-machine head is under way. These include such steps as installing an insulating liner on the head, heating the magazine housings from the outside as well as allowing reactor water to enter the inner housings, and enlarging the cooling system piped into the head. We also have started separate life tests on components of the head and control system. Our objective is to assure a lifetime of 10–20 yr.

Other Approaches to On-Power Refueling

The NPD reactor is not the first or the only one for which on-power refueling is provided or under study. On-line refueling devices are in operation in Canada's NRU reactor at Chalk River, under study for the Hanford production reactors, and planned for Britain's new gas-cooled power reactors.

Hanford's device is the simplest in that it can reload the fuel in a complete channel only. The charging machine, which has been under development for some time, has operated through more than a hundred charge-discharge cycles on a prototype arrangement of simulated tubes as in a production reactor.

NRU's machine also is limited to changing a complete channel of fuel at each operation, but it also can transfer hot fuel from one channel to another. (NRU, which has been operating since 1957, is a dual-purpose research and Pu-production reactor.) So far, the refueling system has carried out more than a thousand successful on-power operations. Thus NRU is the first operational reactor to be routinely refueled this way.

British refueling machines, which are being built for the large commercial gas-cooled power reactors now under construction, are to be located atop the reactor only. These reactors also use slug fuel and the refueling machines also can relocate fuel axially in a channel by removing and then reinserting fuel elements.

The advantage of the more sophisticated systems that can relocate fuel axially is that, for a given reactivity, higher fuel burnups can be achieved than with the simpler systems. Without axial relocation of fuel within the reactor the fuel in a channel has a modified sinusoidal pattern of burnup along its length. By dividing the fuel into two lengths and interchanging the lengths halfway through their life in the reactor the operator can obtain a more uniform burnup along the length of the fuel and a higher total burnup. Subdivision into three parts and appropriate relocation might improve this further.* But we doubt that still more subdivision would produce further increase in burnup, although it might offer manufacturing, handling and building-space advantages and might reduce reactivity and power transients during refueling.

* L. A. Smith, R. J. Atchison. Bidirectional fueling in CANDU—variation in lattice constants through burnup, AECL-833 (1959).

Reactivity Life of Natural U

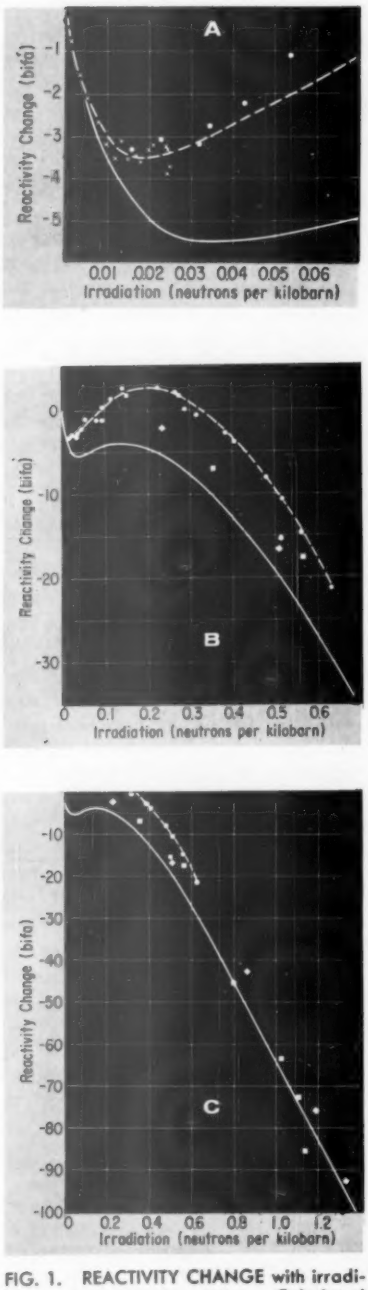


FIG. 1. REACTIVITY CHANGE with irradiation for natural uranium. Calculated values (solid curve) are pessimistic compared with best average of measured values (dotted curve). 1 bifa ≈ 0.1% k (see box, p. 71); 1 n/kb ≈ 4,000 Mwd/tonne

Refined lifetime calculations and the experimental data available to date both reaffirm the original prediction of a 9,750-Mwd/tonne fuel life for CANDU

By ARTHUR G. WARD, *Atomic Energy of Canada Ltd., Chalk River, Ontario*

ONE OF THE MOST IMPORTANT results of the extensive program of physics measurements and calculations for CANDU is the prediction of the expected reactivity lifetime of natural-uranium fuel. Reactor designers need good estimates of the fuel lifetime to be able to calculate a realistic value for the fueling cost. An accurate prediction of the reactivity change with irradiation also helps guide fueling changes toward efficiency and economy.

Experimental measurements have developed greatly in precision since those of 1952 reported at Geneva in 1955 (*1*). The recipes for calculating reactor lattice properties have also improved and are being further refined. Since June 1959, when the first reference design of CANDU was set, results of the calculations have ranged between a high of 10,600 and a low of 8,800 Mwd/tonne U; hence we have had no cause to change our original prediction of 9,750 Mwd/tonne U ± 10%. The calculations agree with experimental measurements of reactivity change with irradiation.

On the basis of all the information to be discussed below, a two-group model calculation of the flattened reactor gives 9,200 Mwd/tonne for the average fuel irradiation. Radial flattening of the reactor requires a two-zone fueling schedule with fuel lifetimes of 11,500 Mwd/tonne for the central zone and 8,900 Mwd/tonne for the surrounding annulus. We continue to study the effects of improvements in our models and in the basic cross-section data (*2*).

Optimum Design

In aiming for maximum fuel burnup in a CANDU-type reactor, many facets of the design must be considered. Desirable features include a very large reactor, optimum spacing of the fuel clusters, the minimum of material in cladding and pressure tubes, a thick D_2O reflector, close spacing of the elements in the cluster, high-density UO_2, low coolant and moderator temperatures and the minimum reactivity reserve for control and poison override.

Technical and financial requirements conflict with those contributing to long burnup. For example, the optimum lattice spacing is below the minimum consistent with good design of the end fittings of the CANDU pressure tubes. A major design problem, then, is the resolution of these conflicts to produce an optimum design.

We have resolved these conflicts through optimization studies that reduce all considerations to a common basis—the effect on predicted power costs. Systematic studies have been carried out with a computer program developed jointly by physicists and engineers (*3*, *4*). As an example, through these studies we could show that a 10.5-in. lattice spacing (a figure preferred by the mechanical engineers) would give a total power cost about 10% higher than the 9-in. lattice spacing finally adopted.

The choice of lattice spacing is of prime importance; the premium on close lattice spacing is high enough to justify considerable complexity in the design of the pressure-tube end fittings. On the other hand, the size of fuel cluster is not very critical except that the pressure-tube diameter should be the minimum consistent with sufficient coolant to transfer the heat at an acceptable coolant velocity. The re-

sults emphasize the cost penalty of each 0.001 in. added to the thickness of Zircaloy fuel cladding or to the pressure-tube thickness. Being thus aware of the power-cost penalty of each mil of Zircaloy, we are unwilling to conceal "ignorance" factors as "safety" factors and insist on reducing engineering uncertainties as far as we can. For example, the optimum outlet coolant temperature depends on the permissible design stress in the Zircaloy pressure tubes; a higher permissible stress raises the temperature at which the optimum-power-cost reactor operates. Hence we are striving to understand the design limits of pressure tubes (see p. 96).

The conclusions of these studies are only as good as the assumptions made in the calculations. The lattice-physics calculations, which lead to a reactivity-lifetime prediction for each reactor design, have uncertainties resulting from errors of input data, approximations and ignorance. We believe the errors are small (~10%), on the basis of the experience already gained from experiment and analysis.

Lifetime Calculations

The U. S., Sweden, France and Canada all reported on reactivity measurements for D_2O-moderated U lattices at the 1958 Geneva Conference. In general, the results show excellent agreement. Our recipes for lattice calculations (*5*) are based on these experimental measurements and should be trustworthy for lattice dimensions and rod sizes comparable to those of the CANDU lattice.

Our lattice recipes refer to a uniform lattice of rods. But the CANDU reactor uses bidirectional fueling in which fuel bundles in adjacent channels move through the reactor core in opposite directions. Hence fuel bundles in adjacent channels have similar properties only near the median plane. For most lifetime calculations of natural-uranium fuel (including the optimization program) we use a simple approximation to allow for the non-uniformities caused by bidirectional fueling. We average properties for the fuel in each channel. This average is equivalent to a "homogeneous" model in which fresh fuel is continually introduced and irradiated fuel is removed, but all the fuel is intimately mixed during the irradiation. Studies of more sophisticated models show that the simple model underestimates (by ~ 400 Mwd/tonne) the reactivity lifetime (*6*). This error arises because the buckling of a lattice with fuel at one-half maximum irradiation is above the irradiation average, and at this time the fuel is in the central plane of the reactor in a position of maximum statistical weight. This effect also contributes to a flux peaking in the axial direction which is above the usual cosine distribution for a uniform lattice; however, this additional flux peaking is canceled out by the reactivity effects of the fuel temperature coefficient and xenon poisoning.

A two-zone fueling schedule will achieve radial flattening in the CANDU reactor, giving a central zone with near-zero radial buckling, surrounded by an annular zone with higher buckling and finally the thick D_2O reflector. FLARE, a two-group program for the Datatron computer (*4*), has been used to study flux distribution, flattening and reflector thickness as related to optimum reactor design. Although these two-group calculations have not yet been compared with experiments, the large diameter of CANDU restricts the importance of the transition regions between the zones, and thus we do not anticipate a large error in reactivity-lifetime predictions owing to the limited validity of the two-group theory. In general, radial flattening reduces the calculated reactivity lifetime but also reduces the capital costs. (The radial-flattened core is smaller for the same power output and hence costs less; at the same time neutron leakage is greater, cutting reactivity lifetime.)

Even with an adequate set of lattice recipes and good models for the CANDU reactor, predictions of reactivity lifetime require many additional experimental data. These include estimates of the short-term reactivity effects of high-power operation, such as poisoning from Xe^{135} and other high-cross-section fission products, the moderator temperature coefficient, the fuel temperature coefficient and the Pu holdup in Np^{239}. Longer-term effects from the gross changes in isotopic constitution of the fuel and the accumulation of low-cross-section fission products are large and require precise calculation. The results of these calculations are particularly sensitive to the balance between U^{235} burnup and Pu production.

The extensive assortment of reactor models, assumptions and input data which goes into the reactivity calculations implies many possibilities for error. Hence the analytic structure we have built up to make these calculations is not a particularly stable one. As we find various building blocks to be faulty, we remove them but we have to replace them with others also of questionable merit. Fortunately, the measurements of reactivity change with irradiation which have been made have given us some measure of confidence in our analytic structure.

Plutonium Production in NRX Fuel

Irradiation (*n/kb*)	*Total Pu production* (*atoms/initial U^{235} atom*) *Measured*	*Calculated*	*Pu isotope*	*Pu isotopic composition* (%) *Measured*	*Calculated*
0.0347	0.01762	0.01748	239	99.267	99.297
			240	0.727	0.696
			241	0.006	0.007
0.0924	0.04595	0.04512	239	98.139	98.154
			240	1.824	1.794
			241	0.037	0.052
0.2268	0.1050	0.1047	239	95.156	95.126
			240	4.535	4.562
			241	0.302	0.312
0.3840	0.1666	0.1663	239	92.109	92.172
			240	7.153	7.075
			241	0.708	0.752
0.6326	0.2489	0.2506	239	87.116	87.396
			240	11.250	10.992
			241	1.516	1.495
			242	0.118	0.116

Irradiation Measurements

For the past twelve years irradiated uranium from the NRX reactor has yielded information about reactivity change with irradiation. Early measurements by the danger-coefficient method compared the reactivity of fresh and irradiated rods in the NRX reactor. More recently, both the "danger-coefficient" and the "pile-oscillator" techniques have been used to measure the changes with irradiation in collaboration with Argonne and Harwell. These experiments provide a close approximation to the problem of predicting fuel lifetime in a reactor.

To complement the reactivity-change measurements, we have carried out extensive chemical and mass-spectrometric analyses of the samples. S. A. Kushneriuk has developed methods of calculating the reaction rates and isotopic compositions of the fuel (*7*). For NRX-irradiated uranium there is excellent agreement between the calculated and measured values for plutonium production and isotopic changes. The table compares the results for five samples used in pile-oscillator measurements.

Ward and Craig (*8*) give the results of a comparison of reactivity-change measurements with calculation and a bibliography of previous work. Natural-uranium samples, 6 in. long and 1.36 in. dia, canned in aluminum, were used in the experiments. These results, and some additional measurements, are shown in Fig. 1. Here the neutron balance in irradiated uranium is expressed in units of barns per initial fissile atom in the fuel (see box). We use the expression "barns per initial fissile atom," or "bifa," when it is necessary to avoid confusion with the value of a nuclear cross section. The ordinate scale in Fig. 1 is the change in bifa with irradiation of the apparent fuel absorption cross section as measured in the GLEEP pile oscillator; a positive sign corresponds to an increase in reactivity. The abscissa scale is in units of neutrons per kilobarn (n/kb).*

There is a discrepancy between experimental results and calculations in the region 0–0.07 n/kb (Fig. 1a). This difference corresponds to ~50% of the poisoning attributable to Sm^{149} and is well outside the expected errors. The easiest explanation of this difference is that high-cross-section impurities are initially present in the samples, but chemical analysis of similar material does not support this explanation. From 0.1 to 0.7 n/kb, the curves for calculation and experiment are nearly parallel. The results in Fig. 1c include measurements on sections cut from irradiated NRX rods. Analysis of these results is not yet complete, but there is reasonable agreement between measurement and calculation. Since nearly all the experimental points show more reactivity than the calculated values, we consider the calculations to be somewhat pessimistic. However, the experimental measurements extend to only ~6,000 Mwd/tonne, whereas the required irradiations for CANDU are ~10,000 Mwd/tonne (6,000 Mwd/tonne represents the limiting exposure obtainable with the metallic-fuel tests; oxide tests recently begun should reach 10,000 Mwd/tonne in the middle of 1961).

Similar measurements have been reported by Gunst, McGarry and Scoville (*9*) for irradiations up to 15,600 Mwd/tonne. Their experimental and theoretical results agree within the experimental error, ~1% in k or ~10 bifa. A detailed comparison with their measurements has not yet been made.

Introducing the "bifa"

Chalk River reports often discuss reactivity changes in fuel in units of the "bifa." Bifa stands for "barns per initial fissile atom" and is obtained from the familiar macroscopic cross section (cm^{-1}) by multiplying by 10^{24} and dividing by the number of initial fissile atoms per unit volume. This unit can apply to any assembly that contains fissile material—e.g., a fuel element, a lattice cell or a complete reactor.

To understand what relationship the bifa bears to $\Delta k/k$ consider a homogeneous reactor in which A (in bifa) is the total absorption cross section. Then $A = \Sigma_x N_x \sigma_{ax}$ where the summation is over all constituents, N_x is the number of atoms of material x per initial fissile atom, and σ_{ax} is the total absorption cross section. (In a heterogeneous reactor suitable flux weightings must also be included.) Similarly $Y = \Sigma_x N_x \sigma_{fx} \nu_x$ is the yield cross section (in bifa) where ν_x is the number of neutrons per fission. Then $Y/A = \eta$ (the yield of fission neutrons per thermal neutron absorbed) which occurs in the two-group formula

$$k = \eta \epsilon p f \qquad \text{(in this example, } f = 1\text{)}$$

The change in reactivity due to a change in η is

$$\Delta k/k = \Delta\eta/\eta = (\Delta Y/\eta - \Delta A)/A$$

In an efficient natural-uranium reactor $A \cong 1{,}100$–$1{,}300$ bifa (say, 1,200). Hence the addition of an absorbing material to our hypothetical reactor so that $\Delta A = 1$ bifa and $\Delta Y = 0$ would correspond to a change $\Delta k/k = 1/1{,}200 \cong -0.08\%$.

Fission-Product Poisons

The buildup of fission products in irradiated fuel causes large reactivity changes. Calculations of this poisoning are revised as new data become available; the trend has been to a marked *increase* in the calculated poison. For calculation we class the fission products as "high cross section" or "low cross section."

The "high cross section" fission products, Xe^{135}, Sm^{149}, Sm^{151}, Cd^{113}, Eu^{155}, Gd^{155} and Gd^{157}, are usually treated as saturated poisons (i.e., in equilibrium concentration), with yields appropriate to isotopic composition of the fuel. A remeasurement of the yield of Xe^{135} in Pu^{239} fission gave a value of 7.25% (*10*), significantly different from the older value of 5.3%. This change alone resulted in a decrease of ~300 Mwd/tonne in the predicted burnup for CANDU.

The "low cross section" fission products comprise the majority of the fission products. From the mass of available data on neutron-capture cross sections and yields for fission products,

* A kilobarn is an area of 10^{-21} cm^2; hence 1 neutron per kilobarn is equivalent to an irradiation dose of 10^{21} $n/cm^2 \approx 4{,}000$ Mwd/tonne. The relation between n/kb and Mwd/tonne is nearly linear.

one can calculate the poison cross section resulting from an average fission and its subsequent changes with irradiation. Fortunately, the fission products separate reasonably well into those with short half-lives, in which neutron capture cannot compete with radioactive decay, and those which are stable or long-lived. For this reason the poison concentration is not sensitive to the flux level of irradiation. A good fit to the calculated values can be obtained using "three pseudo fission products" with yields assigned to the different fissile nuclides (see box on this page).

Walker (*11*) has revised the pseudo-fission-product yields and cross sections to allow for the resonance capture in fission products. The current values (see box) represent a considerable increase over those previously in use. The initial poison contribution of "low-cross-section" fission products is 63.8 barns per fission from U^{235} fission and 74.1 barns per fission from Pu^{239} fission. This revision in the yields and cross sections of the fission products is equivalent to a decrease of ~1,000 Mwd/tonne in the predicted burnup for CANDU. This is only one of the revisions that have caused the predicted value for the lifetime to oscillate between the 8,800-Mwd/tonne and 10,600-Mwd/tonne limits mentioned before.

Pseudo Fission Products

Chalk River has developed a quite general method for mocking up neutron absorption by the "low cross section" fission products (i.e., all fission products except six high-cross-section isotopes). The method assumes the buildup of three "pseudo fission products"—a 50-barn fission product, a 300-barn fission product and an 800-barn fission product.

The total absorption σ_{avg} in barns introduced for this group per average fission and its subsequent burnout with irradiation I (in neutrons per kilobarn) is given by $\sigma_{avg} = 50y_{50}e^{-0.05I} + 300y_{300}e^{-0.3I} + 800y_{800}e^{-0.8I}$. Here y_x = yield of pseudo fission product of cross section x barns given in the table. When I = 0, σ_{avg} = total initial poison ($\Sigma y_i\sigma_i$) given in the right-hand column of the table.

	Pseudo-fission-product yield per fission			*Total initial poison*
Fissile nuclide	*50 barns*	*300 barns*	*800 barns*	*(barns per fission)*
U^{233}	0.583	0.111	−0.00497	58.4
U^{235}	0.698	0.118	−0.0079	63.8
Pu^{239}	0.802	0.178	−0.0244	74.1
Pu^{241}	0.817	0.168	−0.0128	81.1

The numerical expression given for σ_{avg} should be valid for any thermal reactor in which the fission products remain in the fuel.

Experimental Program

The measurements of reactivity change with irradiation are continuing. UO_2 samples are being irradiated in the NRU reactor to ~10,000 Mwd/tonne, and the reactivity changes will be measured in the Pool Test Reactor at Chalk River. The samples will also undergo chemical and isotopic analysis.

Precise estimates of the reaction rates in fuel-rod assemblies require a knowledge of the neutron spectrum in the fuel assembly. Measurements are being made, in a loop installed in ZEEP, of neutron-reaction rates in a mock-up CANDU fuel assembly. Bigham has measured the variation of the $\sigma_f(Pu^{239})/\sigma_f(U^{235})$ ratio with coolant temperature relative to the value of this ratio for a 20° C Maxwellian neutron spectrum. With coolant temperature equal to moderator temperature this ratio shows a 14% increase above the Maxwellian value; this is attributable to the reactor spectra in the rod assembly.

The changes as a function of coolant temperature are appreciable both for reactivity-lifetime calculations and for calculations of the coolant temperature coefficient of reactivity. We plan further measurements that will use hot air rather than hot D_2O in the loop to separate the contributions due to D_2O coolant temperature from those due to the heated oxide. Measurements of the scattering neutron cross sections and angular distributions for fuel-assembly materials are now under way in a joint Harwell–Chalk River experiment; these detailed measurements will provide basic data for the calculation of reactor neutron spectra.

Precise measurements of the "initial conversion factor" (the number of Pu^{239} atoms produced per U^{235} atom destroyed) are needed to make accurate calculations of the reactivity lifetime. Several measurements of NRX irradiated fuel have confirmed a value of 0.76–0.77 for NRX. Unfortunately, measurements of the required precision (~1%) are not available for UO_2 lattices, and the values used at present derive from the "lattice recipes." Activation measurements of the required precision in zero-energy lattices are possible with present experimental techniques. One difficulty is the measurement of the $U^{239} \xrightarrow{\beta} Np^{239} \xrightarrow{\beta} Pu^{239}$ activity with negligible corrections for fission-product γ-rays. A coincidence method based on the pattern of γ-ray emission following Np^{239} β-decay has given promising results. The method resembles that described by Sher (*12*). A preliminary result has given agreement between measurement and calculation within ~1% for a fuel geometry closely resembling the CANDU lattice arrangement.

BIBLIOGRAPHY

1. D. G. Hurst in "International Conference on the Peaceful Uses of Atomic Energy," vol. 5, p. 111 (United Nations, New York, 1956)
2. D. J. Hughes, B. A. Magurno, M. K. Brussel. Nuclear cross sections, BNL-325 (1960)
3. M. F. Duret, R. Marriott. A computer program for optimization studies, AECL-911 (1959)
4. W. J. Henderson, D. G. Hurst. The effect of flux flattening on the economics of heavy water moderated reactors, AECL-949 (1959)
5. D. W. Hone, E. Critoph, M. F. Duret, R. E. Green, A. Okazaki, R. M. Pearce, L. Pease. Natural-uranium heavy water lattices, experiment and theory, AECL-615 (1958)
6. L. A. Smith, R. J. Atchison. Bi-directional fuelling in CANDU—variation in lattice constants through burn-up, AECL-833 (1959)
7. S. A. Kushneriuk. Effective cross sections and neutron flux distributions in a natural uranium rod, AECL 497 (1957)
8. A. G. Ward, D. S. Craig. Analysis of measurements of the reactivity change with irradiation for natural uranium samples, AECL-814 (1960)
9. S. B. Gunst, E. D. McGarry, J. J. Scoville. The reactivity of natural UO_2 irradiated to 6×10^{21} n/cm², *Nuc. Sci. and Eng.* **7**, 407 (1960)
10. H. R. Fickel, R. H. Tomlinson. The cumulative fission yields of 21 heavy mass nuclides produced in the thermal fission of Pu^{239}, *Can. J. Physics* **37**, 926 (1959)
11. W. H. Walker. Yields and effective cross sections of fission products and pseudo-fission-products, CRRP-913 (1960)
12. R. Sher. γ-γ coincidence method for measuring resonance escape probability in U^{238} lattices, *Nuc. Sci. and Eng.* **7**, 479 (1960)

Reactor Safety in Canada

The Canadian approach is to be quantitative where possible—first to define an acceptable numerical risk, then to gather statistics to show that the reliability of equipment and human judgement meets this standard. Duplicate components and continuous testing are ways to build in the perfection needed

By GEORGE C. LAURENCE, *Atomic Energy of Canada Lmtd., Chalk River, Ontario*

PROTECTION against reactor accidents in Canada does not differ greatly from the practice in the United States and the United Kingdom. Licensing authorities in all three countries evidently feel that, although safety measures are costly, there should be no relaxation until there is much more experience. In Canada, however, our awareness of the cost has made us re-examine safety requirements. It has made us look for new systems that will provide the same or better protection at less cost.

It is difficult to claim that a reactor is safe unless one can express the degree of safety in terms that permit comparison with a standard. We need to express risks quantitatively, even if the limits of uncertainty in our estimates are several orders of magnitude apart. This is a point Siddall (*1*) has emphasized, but many of his readers were impressed more by the difficulties of making quantitative appraisals. Nevertheless we are endeavoring in Canada to discuss safety and dependability in quantitative terms, because we feel that, unless probabilities are considered, concepts such as the "worst credible accident" are of very little help. We need numbers that designer, operator and licensing authority can all understand and can use for setting design and operating requirements.

First attempts to estimate unreliability depend greatly on instinctive judgement, but we look for more evidence from experience to improve our judgements and we feel that we are making progress. The development of protective equipment that can be tested under power and control systems that are continually self-monitoring makes our task easier.

Because there is so little experience to provide a factual background, wide differences of opinion are to be expected on reactor safety. This article discusses some of the thinking in Canada but does not report every point of view.

We do not mean to suggest that the protective measures discussed in the following sections are essential for all reactors. The aim is to define the degree of safety required but not to restrict the means by which it is attained.

Acceptable Risk

Our purpose is to maintain a standard of safety in the operation of nuclear reactors better than that of most other industry. To calculate an acceptable risk for nuclear reactors we start by multiplying the risk in deaths per year for all industry by the ratio of the annual investment in reactors to the annual investment in other industry. We then divide by ten to be sure that our standard is better than that for most other industry.

On this basis the acceptable risk for a power reactor of several hundred Mw(th) is of the order of 10^{-2} deaths per reactor-year (*1*). For a small research reactor it is of the order of 10^{-3} per reactor-year. We consider only accidental deaths because non-fatal injuries are not easily defined—how does one compare the obvious loss of a limb with the uncertain probability of disease in ten years?

The operating experience with reactors is still insufficient to give the statistics needed for a precise estimate of the probable future casualty rate. Nevertheless, we should attempt an estimate, if only to avoid the impression that we expect perfection on the one hand or are complacent on the other.

Although there have been many failures of equipment and judgment that have caused physical damage to reactor plants and have required costly repairs and decontamination, the more than 17 years of reactor operation throughout the world have resulted in only three deaths and very few overexposures of persons. The two most costly accidents, NRX in 1952 and one of the Windscale reactors in 1958, caused no personal overexposure. We thus have some basis for concluding that the risk from the more probable kinds of accidents is acceptably small.

But the great effort and expenditure on reactor safety has not been prompted by anxiety about the more probable kinds of accidents. It is dictated by fear of the single accident that would raise the average casualty rate above the acceptable level, e.g., an accident

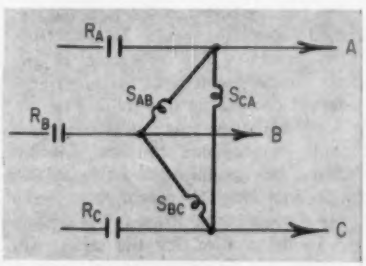


FIG. 1. RELAY NETWORK rejects spurious signal on one of three identical channels. Wrong signal on B trips relays S_{ab} and S_{bc} which in turn open relay R_b

causing several hundred deaths. We should, therefore, define a "major" accident and distinguish it from the more probable accidents. We will take as a major accident one in which at least ten persons are killed by radiation. Deaths that are not due to radiation exposure are not included.

Discussions of the "worst credible accidents" do not exclude the small possibility of a single accident producing a few thousand deaths (*2*). But to suggest that the *average* loss of life expected in major accidents of large reactors is more than 1,000 would go far beyond the limits of credibility.

If the maximum acceptable risk is 10^{-2} deaths per reactor-year and the average number of deaths per major accident is less than 1,000, the number of major accidents should not exceed 10^{-5} per reactor-year. This limit is so low that experience alone cannot tell us whether we have succeeded in reaching it. We can only infer the probable accident rate by estimating the probability of coincidence of causally independent conditions. Suppose we can establish that the frequency of equipment and operating failures capable of causing a major accident is 10^{-1} per reactor-year, and that the probability of the protective devices failing to operate when called upon is less than 10^{-3}, we may then conclude that the probable frequency of major accidents is less than 10^{-4} per reactor-year.

(Before accepting this conclusion we must be confident that the frequency of simultaneous faults in both the equipment and the protective devices due to a common cause, such as an earthquake or lax management, is also less than 10^{-4} per reactor year.)

Since in the example given above the total probable rate of major accidents is not below the required limit of 10^{-5} per reactor-year, additional protection, such as containment, would be needed.

The limits chosen in this example are small enough to be useful, but large enough to be attainable. However, they must also have another very important quality: they should not be so small that it is impossible to convince anyone that they have been achieved.

Dangerous Failures

The two most important classes of dangerous failures are faults in the reactivity-control system that tend to produce a power excursion, and faults in the primary cooling system, such as rupture of piping or stoppage of pumps, that could result in overheating of the fuel.

A control system contains so many components it is unreasonable to expect less than 1 unsafe fault per year. If each unsafe fault meant an increase in reactor power stopped only by the protective system, and the unreliability of the protective system was 10^{-3}, the expected frequency of excursions that are not safely stopped by the scram system would be 10^{-3} per reactor year. An expectation of 10^{-3} unarrested excursions per year is unacceptably high for large power reactors. However, at least a tenfold improvement can be obtained by the use of a triplicated automatic reactivity-control system described in a later section; this then reduces the expectation of unarrested power excursions to less than 10^{-4} per reactor-year. We use multiple control systems in the large Canadian reactors for this reason.

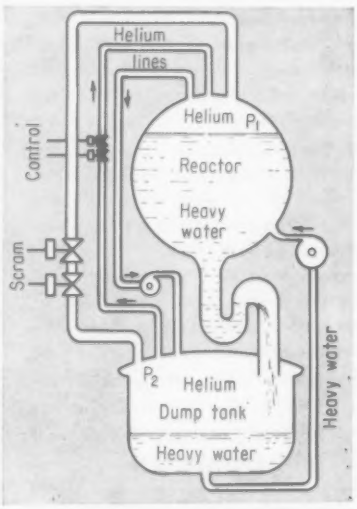
Most of the primary cooling system of a reactor is constructed to well established engineering standards. The probability of a major rupture in piping and equipment outside the reactor causing a loss of the primary coolant can be assumed to be less than 10^{-4} per reactor year and, indeed, the experience of the ASME Boiler and Pressure Ves-

Moderator Level Control

Canadian power reactors will be controlled by adjusting the depth of heavy water in the reactor vessel (5, 6). The important advantage of moderator level control is its great simplicity with no moving mechanical parts in the reactor core where maintenance would be difficult. Pumps move the heavy water into the vessel at a constant small rate from the dump tank below; the water returns to the tank through a goose-neck (see figure). The difference in helium pressure between the vessel and the dump tank determines the depth of heavy water in the vessel. Only this difference in gas pressure prevents the heavy water from falling out of the reactor. Helium is pumped at a nearly constant rate from the reactor to the dump tank and returns through three gas lines (only one shown in the figure) connecting the top of the tank to the top of the reactor.

The control signals determine the setting of the six valves on the three lines connected as shown in Fig. 2d. The valve settings vary continuously with the signal strength from fully open to fully closed. With all six valves at a certain intermediate setting the flow of gas through them just equals the rate at which gas is returned to the reactor vessel by the pumps, and thus a constant pressure is maintained which keeps the depth of heavy water in the reactor vessel constant. If a fault in one signal channel were to completely stop the flow through two of the gas lines the valves in the third line connected to the remaining two signal channels would open enough to compensate.

A protective scram consists in dumping the heavy-water moderator into the dump tanks. Three large gas pipes connect the top of the reactor to the top of the dump tank (only one is shown in the figure). Normally, two solenoid valves in series in each pipe prevent the flow of gas through the three pipes. Opening the two valves in one of the lines will quickly equalize the gas pressures in the two vessels and the heavy-water moderator will drain quickly from the reactor. The solenoids of the six valves connect to three parallel scram circuits as shown in Fig. 2d. A test signal on only one channel or a fault in only one channel will not dump the moderator. At least two channels must be defective to make the system inoperative.



To make sure that the scram will handle the maximum rate of reactivity increase, the moderator pump-up rate is kept very small compared with the dump rate.

sel Committee and others shows that the performance of high-pressure systems is very much better than this. To apply this figure to parts inside the reactor, or to a pressure shell surrounding the core, we must show that irradiation and exposure to other operating conditions do not cause deterioration of properties that would make the good experience in other industry no longer relevant.

Through duplication of pumps and automatic switching on power failure to a standby source, it is not difficult to reduce the total expectation of a dangerous loss of flow to below 10^{-4} per reactor-year. The information on frequency of power failure and pump faults needed for these estimates is easily obtained. The same degree of protection against excess temperature and pressure can be provided.

From more detailed consideration of the performance of this kind of standard equipment, components and instruments in other industry, and of special equipment in reactor plants, we believe that the probability of a major accident can, by good design and operation, be made less than 10^{-4} per reactor year for large reactors without including special containment features. Containment provisions then will reduce this probability considerably further to ensure that the total probability of major accidents is less than 10^{-5} per reactor year.

Continuous Testing

In Canada we prefer automatic control (*3, 4*) for large reactors. With control preset for the power desired, the system brings the reactor from shutdown to a demanded power and it holds it at this power. It raises the power at a safe rate without any manual adjustment. With automatic control, safety does not depend on the continuous, undistracted watchfulness of an operator. It permits the operator to give greater attention to the many instruments in the control room. However, reliance on automatic control requires frequent testing and prompt maintenance.

A simple method of testing a control circuit is to compare its performance with a similar circuit. Gross disagreement indicates a fault in at least one of them. It is improbable that two defective control circuits will agree closely, and very improbable that three should agree.

By operating with two or more parallel circuits controlling the reactor we have the means of testing them continuously since each is a check of the other. A large discrepancy between their performances actuates an alarm.

To prevent the defective signal from influencing the reactor a system of relays (connected as shown in Fig. 1) can be used to reject the spurious signal. This method is used in NRU (*5, 9*). A discordant signal on channel B, for example, closes the two relays, S_{ab} and S_{bc} connected to it which in turn cause relay contacts at R_b to open, disconnecting the defective channel B.

In a different method of suppressing the erroneous signal, proposed by Siddall (*6*) three servo loops in parallel control the power of the reactor. Signals proportional to power are amplified in each loop and control the motion of control rods or the flow of heavy water moderator to change reactivity. Reactivity increases or decreases when the observed power P_0 is less or more than the demanded power P_D. The amplifiers are designed so that output signal cannot pass outside the limits $\pm L$, but within these limits the output is determined by $(P_0 - P_D)$ with a high amplification gain. The minimum signal that can be caused by a fault in one channel is $-L$. This would cause the reactor power to increase until the signals in the other two channels are increased to $+L/2$. By making the range $\pm L$ small and the gain within it great the departure from the demanded power can be limited to a few per cent. A wide disagreement between the signals of any two channels would be announced by a warning alarm controlled by relays connected between the three channels. Another method is an alarm that would sound if any two of the output signals are at opposite extremes of the operating range $\pm L$.

Safeguard Unreliability

The *unreliability* of a protective provision is the fraction of time that faults that render it ineffective are allowed to remain. We assume that the protective provision is completely *effective* when free from faults; i.e., it prevents an equipment failure from causing a major accident. Note that "unreliability" refers here to the probability of failure to operate but "effective" describes what the operation can do.

There are two kinds of faults—those that are immediately evident and faults that are only revealed by test and inspection. The part of the unreliability due to obvious faults is

$$U_{obv} = M_{obv}/T_{obv}$$

where M_{obv} is the average time required to correct the fault and T_{obv} the average interval between the occurrence of faults (i.e., the reciprocal of their frequency). The part due to faults that must be found by testing or inspection is

$$U_{test} = (M_{test} + I_{test}/2)/T_{test},$$

where I_{test} is the interval between tests, M_{test} is the time required to replace the instrument, T_{test} is the average interval between the faults.

The most frequent faults may be expected in small components of instruments. It is important that the instruments be designed so that they can be quickly replaced. Experience at Chalk River shows that, if maintenance service is available whenever the reactor is operating, the time required to replace the defective instrument M_{obv} or M_{test}, need not average more than 1 hour. For U_{obv} to be less than 10^{-3}, T_{obv} must exceed 6 weeks. T_{obv} can be determined by a few months test with simulated operation conditions before the plant is operated. If no failures occur during this test it should give sufficient confidence in the device to allow plant start-up. Continued operation without failure during subsequent weeks would strengthen confidence that U_{obv} is less than 10^{-3}

The interval I_{test} between tests must be short to obtain a low unreliability U_{test}. For this and other reasons it is very desirable to design protective devices so that it is unnecessary to interrupt plant operation to make tests for faults. This can be done for most parts of the equipment by duplication, as discussed later, and if the tests are simple, they can be made every 8-hour shift, so that $M_{test} + I_{test}/2$ is about 5 hours. In this way one can make U_{test} less than 10^{-3} without requiring that T_{test} be so large as to rule out a preliminary measurement of it before starting operation plant.

Duplicating Parts

The frequency of faults in equipment that contains many small components may be quite high. Where it is difficult to make the interval T between

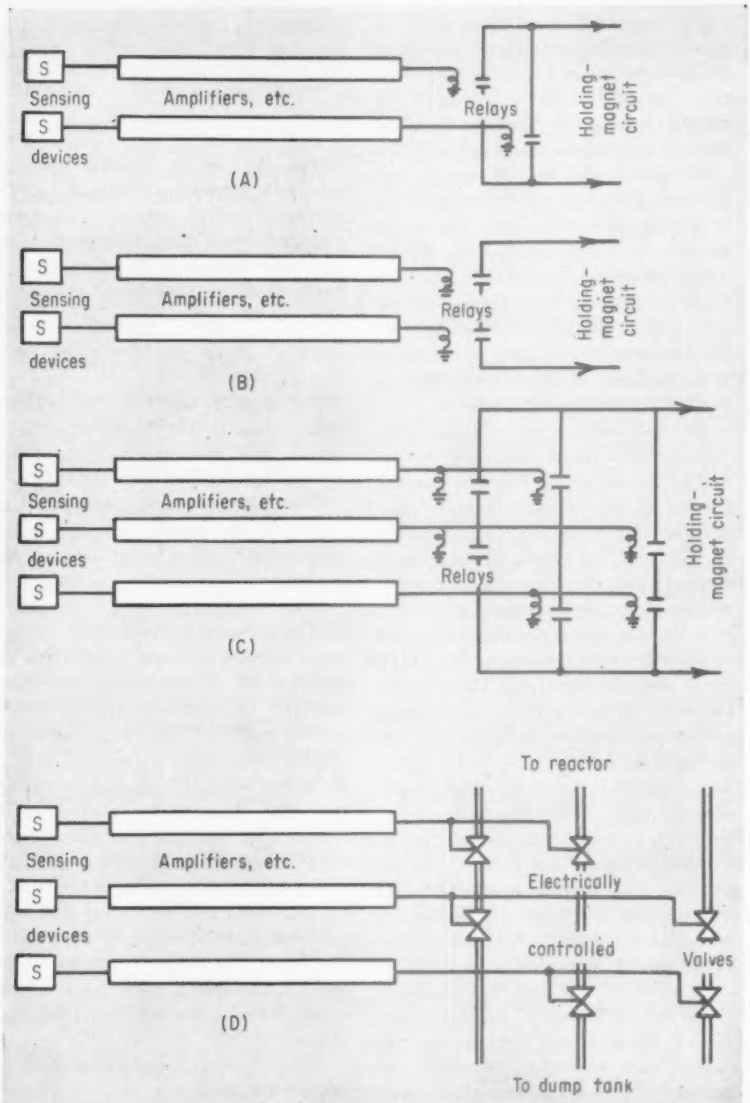


FIG. 2. MULTIPLE SAFETY CIRCUITS improve reliability of reactor safeguards. A, B and C are three versions of scram in which signal operates relays to break current to magnets holding scram rods. D is circuit C adapted for moderator-dump scram to be used on CANDU power reactor

faults long and the interval I between tests short, the unreliability U_{test} can be made small by duplicating the more vulnerable parts in such a way that both sets of parts must contain faults at the same time to render the system ineffective. Then

$$U_{test} = \frac{(M + I/2)^2}{T^2} + \frac{(M + I/2)}{T'} + \frac{(M + I/2)}{T''}$$

where T is the average interval between the independent faults in duplicated parts of the system, T' is the average interval between faults in the duplicated parts that are not independent because they are produced together by the same cause, and T'' is the average interval between faults in parts that are not duplicated.

The first term in this expression can be made quite small. It may be possible to eliminate the third term by complete duplication of the system; otherwise the unduplicated components should be few and of types known to be very reliable. The second term, the probability of concurrent faults in the two parallel branches of the system resulting from a common cause, is the most uncertain but very important. Some causes that contribute to the second term, such as failure of a common power supply, can be excluded by fail-safe design. Others can be converted from this class of faults to obvious faults not requiring test by having them actuate alarms. Normal experience in other plants gives us confidence that the probability of coincident faults caused by fire, flood or lightning is negligible.

The most difficult part of the second term to assess is the probability of errors in operating or maintenance because these are subject to such influences as changes in policy and attitudes of personnel. The probability of faults due to maintenance errors existing in more than one channel at the same time is reduced greatly by the one-channel-at-a-time rule. This rule requires that, after a channel is repaired, it must be tested in operation and shown to be operating properly before repairs are started on another channel. A double fault, then, would depend on the repairman's simultaneously breaking this rule and repeating the mistake. We feel that a reasonable assumption (which we are still unable to support by statistics) is that the probability of such an event is less than 10^{-3} per year.

Any claim that the unreliability of a protective device is much less than 10^{-3}, based only on the theoretical probability of the multiple coincidence of failures that are supposed to be independent, should be regarded with caution because of the difficulty of estimating the second and third terms of U_{test} when they are small. There may be little to gain, therefore, by increasing the multiplicity of components more than is necessary to reduce the unreliability below 10^{-4}.

We may conclude that a factor of unreliability of 10^{-3} is usually attainable but a much lower factor would take a long time to demonstrate. However, the purpose of this order-of-magnitude estimating is not to establish a standard of approval but to compare the importance of different causes of unreliability.

Testing Safety Equipment

The low factor of unreliability that is required is difficult to maintain unless tests are frequent and replacement of defective parts is quickly done. Also frequent testing is needed to know that no deterioration is taking place. Frequent shutdowns of large reactors are costly and, therefore, the protective equipment of such reactors in Canada is designed so that it can be tested (excepting a few components) while the reactor is operating. The equipment is designed so that components can also be adjusted or replaced safely during operation.

The operating policy at Chalk River states that, where maintenance may safely be done under power, it should not be done with the reactor shut down. This policy is based on the experience that maintenance mistakes are more apt to remain undiscovered when the equipment is idle and can accumulate to render both sides of a double-channel system defective when the plant is restarted. Similar mistakes made while the equipment is operating are more quickly discovered so that the probability of coincident faults is reduced.

Testing and maintenance during operation is made possible by more than one channel of equipment in parallel so arranged that trip signals must be delivered by at least two of them to cause a scram (*7*). This is illustrated by the diagram of the two-channel system in Fig. 2a. A fault condition detected by the two sensing devices S on the left generates independent trip signals in the two channels of amplifiers which cause the two relays R to open contacts in parallel. This breaks the circuit of the holding magnets of a group of shut-off rods so that the rods are free to fall into the reactor. A simulated fault condition applied for test purposes to only one sensing device will confirm that the channel is operative by opening one of the relay contacts. The test does not cause a scram because the second contact remains closed. Another advantage of the circuit is well known; it reduces the frequency of scrams caused by faults in the scram system. A trip signal in only one channel actuates an alarm to indicate the presence of a fault.

While the two-channel system in Fig. 2a reduces unreliability by permitting frequent testing and prompt maintenance, it makes no use of the improbability of coincidence to reduce unreliability. The channel system in Fig. 2b in which the contacts in the shut-off rod-holding-magnet circuit are in series, does exploit the advantage of improbable coincidence in faults in two channels, but can not be tested without causing a scram.

Figure 2c shows a three-channel system that combines the advantages of 2a and 2b. A single channel only will not cause a scram, but a fault in one channel only will not incapacitate the system. This circuit with various modifications is used in a number of Canadian reactors. The simpler circuit 2b is suitable for small research reactors that are not required to operate for more than a day at a time, because testing can be done frequently in periods of shutdown.

Hazards During Shutdown

Research reactors have an added hazard in that large changes in reactivity are easily caused by inserting research apparatus or materials in the reactor. This is particularly true of critical assemblies for lattice experiments and of reactors that are "spiked" with highly enriched fuel to compensate for unusual neutron losses in research equipment.

For example, an error may be made in estimating the effect of a change in the loading made while the reactor is shut down. A large increase in reactivity caused by the change may not be noticed because the reactor is heavily poisoned with Xe^{135}. As the Xe^{135} decays reactivity increases and reaches criticality. If all of the shut-off rods are already in the reactor they can provide no further protection to prevent excessive power.

It is the rule at Chalk River that when a reactor is shut down by insertion of shut-off rods, whether by intention or protective scram, some of the rods, known as the safety bank (*8*), are immediately withdrawn again. To change the loading of the reactor with all shut-off rods inserted is forbidden. Maintenance of reactor equipment, including the protective equipment, while all rods are inserted is avoided.

Safety During Operation

Increasing emphasis is being given in Canada to safety in operation. The experience of the NRX accident of 1952 has made us extremely careful. The operation of large reactors normally follows detailed written procedures. When a new situation arises or there is reason to depart from approved procedures, written approval must be obtained from a senior officer designated for that purpose. Training receives much attention and is kept fresh by frequent check-out.

A low failure rate of equipment and procedure and low unreliability of protective measures are not qualities which once built in remain unimpaired and can be forgotten. They depreciate rapidly unless constantly watched and maintained. For this reason increasing emphasis is placed on frequent review of all failures and faults so that the operator knows if there is an increase in failure rate or unreliability and can correct it. If unreliability increases, owing to frequent faults in a component for example, the operator can decrease it by using a better component, by more frequent testing or by quicker replacement of defective instruments. A very important contribution to the safety of a reactor is the correction of weakness that is revealed during commissioning and early operation.

The operator must know whether or not his equipment is in good working order and is as reliable as the design intended. To know this tests must be made regularly in a prescribed routine, records must be kept of failures of components and these data must be examined and interpreted frequently.

BIBLIOGRAPHY

1. E. Siddall. Statistical analysis of reactor safety standards, NUCLEONICS **17**, No. 2, 64 (1959)
2. Theoretical possibilities and consequences of major accidents in large nuclear power plants, WASH-740 (1957)
3. C. G. Lennox, A. Pearson. NRU reactor neutron level control system, IRE Transactions on Nuclear Science NS-5 (1958)
4. C. G. Lennox, A. Pearson. Thermal power control of the NRU reactor, IRE Transactions on Nuclear Science NS-5 (1958)
5. Winnett Boyd, F. W. Gilbert, G. C. Laurence, I. N. MacKay. The NRU reactor in "Proceedings of the Second U. N. Conference on the Peaceful Uses of Atomic Energy," vol. 10 p. 128 (United Nations, Geneva, 1958)
6. E. Siddall. Highly reliable control systems for a 200 Mw power reactor, AECL-685 (1958)
7. E. Siddall. Reliable reactor protection, NUCLEONICS **15**, No. 6, 124 (1957)
8. W. B. Lewis, A. G. Ward. An appreciation of the problem of reactor shut-off rods with special reference to the NRX reactor, AECL-590 (1953)
9. A. Pearson, E. Siddall, P. R. Tunnicliffe. The control of Canadian reactors, in "Proceedings of the Second U. N. International Conference on the Peaceful Uses of Atomic Energy, vol. 11, p. 372 (United Nations, Geneva, 1958)

Organic-Cooled Deuterium-

We hope to build a reactor experiment to establish the feasibility of the OCDR concept for power reactors. But first we must optimize reactor design, find improved organics and develop suitable sintered-aluminum-powder materials for cladding the fuel

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THE ORGANIC-COOLED DEUTERIUM-MODERATED REACTOR uses heavy water as moderator, but extracts heat from the fuel channels with an organic coolant. It combines the low fueling costs resulting from D_2O moderation and "once through" natural-uranium fuel, with the low capital costs expected from the use of organic coolants. Capital costs, and to some extent maintenance costs, are reduced through such properties of organic coolants as low vapor pressure, good radiation and thermal stability, noncorrosiveness at high temperatures, low induced radioactivity and relatively low price. Such properties eliminate the need for high-pressure construction, extend the use of carbon steel and aluminum, permit the use of industrial-type pumps and fittings and make possible high bulk-coolant outlet temperatures. But some penalty must be paid in terms of radiation damage to the coolant with its associated makeup costs, and possibly in reduced neutron economy as compared with D_2O-cooled reactors.

The OCDR concept was first investigated by Canadian General Electric in 1957. Preliminary appraisals of power plants using this concept were so attractive that CGE undertook in 1958 a more detailed design and cost appraisal of a 150-Mw OCDR power plant (*1*). The results confirmed the earlier impressions of the attractiveness of this concept. Following this study, agreement was reached with Atomic Energy of Canada Ltd. to undertake an Organic-Cooled Reactor Program and from this point there has been a growing Canadian effort in this field.

Specifically we are designing an Organic-Cooled Deuterium-Moderated Reactor Experiment (see Fig. 1) under the sponsorship of AECL. The decision to build OCDRE will be based on the outcome of the conceptual design and development programs now in progress, and on the results of a study of the cost of energy from large organic-cooled reactors. The reactor is intended for installation at AECL's new Whiteshell reactor development site near Winnipeg. If approved by AECL, criticality would come in 1964.

The case for the organic-cooled reactor assumes first, that an organic coolant will be available with a satisfactory combination of properties when used with maximum bulk temperatures in the range of 750°–800° F and second, that a fuel-sheathing material will be available that is compatible with the coolant, can be produced and fabricated at reasonable cost and can serve at temperatures close to 900° F.

The bulk of the work in Canada, carried out jointly by CGE and AECL, has been directed towards a better understanding of the properties of various possible organic coolants and evaluating materials suitable for use in organic and D_2O environments. The initial objective was to set tentative specifications for materials for an experimental organic-cooled reactor.

Organic Coolants

Investigators in the U. S., UK and Canada have been learning a good deal about the properties of organic coolants. Although two years ago each group was using its own unique heat-transfer correlations, improved measurements show that standard correlations now can be used (*2*). Experience with the U. S. Organic Moderated Reactor Experiment shows that fouling of fuel elements depends largely on certain constituents of the organics, which can be removed so that fouling can be eliminated (*3*). Fouling is also much reduced if coolant velocities are held within certain limits that happen to be desirable for other reasons in heavy-water moderated reactors.

Experiments indicate that nucleate boiling in organics can control transient hotspots. Disposal of organic waste by burning has been demonstrated (*4*). Radiation-damaged organic coolant has been purified by continuous distillation in a prototype rig. Progress has been made in the disposal of particulate impurities, although there is still room for improvement. Agreement has not yet been reached on the rate of breakdown caused by irradiation, but experimental techniques (particularly dosimetry) are now much improved and a great deal of information has been accumulated.

AECL and we will explore new coolant possibilities with the aims of improving physical properties generally, especially radiolytic and pyrolytic stability, and reducing cost. Phenyl derivatives, the organics receiving most attention in the past, will not necessarily prove most economical in the long run. For example, irradiations of alkylphenanthrene by Atomics International suggest that it has higher stability than the usual terphenyl mixtures. It also contains a lower proportion of hydrogen to carbon, an advantage in D_2O-moderated reactors. What's more it's substantially cheaper than the terphenyls. Of course much more would have to be known about the behavior of alkylphenanthrene under irradiation before it could be used in a reactor. In due course there are sure to be other materials that will merit investigation.

It is interesting to note that the type or organic best suited for use as a *moderator* in an organic-moderated reactor is not likely to prove most economical as a *coolant* in a reactor moderated by another material, say heavy water as in our case. In an organic-moderated-and-cooled reactor the volume of organic exposed to irradiation is many times as great as the volume exposed to irradiation in a heavy-water-moderated organic-cooled reactor. For example, in a conceptual 150-Mw(e) OCDR design the organic coolant in the core represents only 1.7 wt% of the total moderating material. The organic-damage rate in such a reactor should be only 2–4% of that for an organic-mod-

Moderated Reactors

erated-and-cooled design (*1*). Thus whereas the radiation-damage rate and low replacement cost rank high in the requirements for an OMR, a property such as low vapor pressure (which lowers capital cost) might be more important in an OCDR.

Fuel Design

Originally it was assumed that the presence of a hydrogen-containing coolant in a multiple-element fuel assembly for a D_2O reactor would seriously affect reactivity. Early proposals assumed that rather expensive fuel configurations would be required to limit the coolant to a bare minimum. More recent calculations and experiments indicate that the extra coolant present in a fuel element that is most economical to manufacture will not exact a

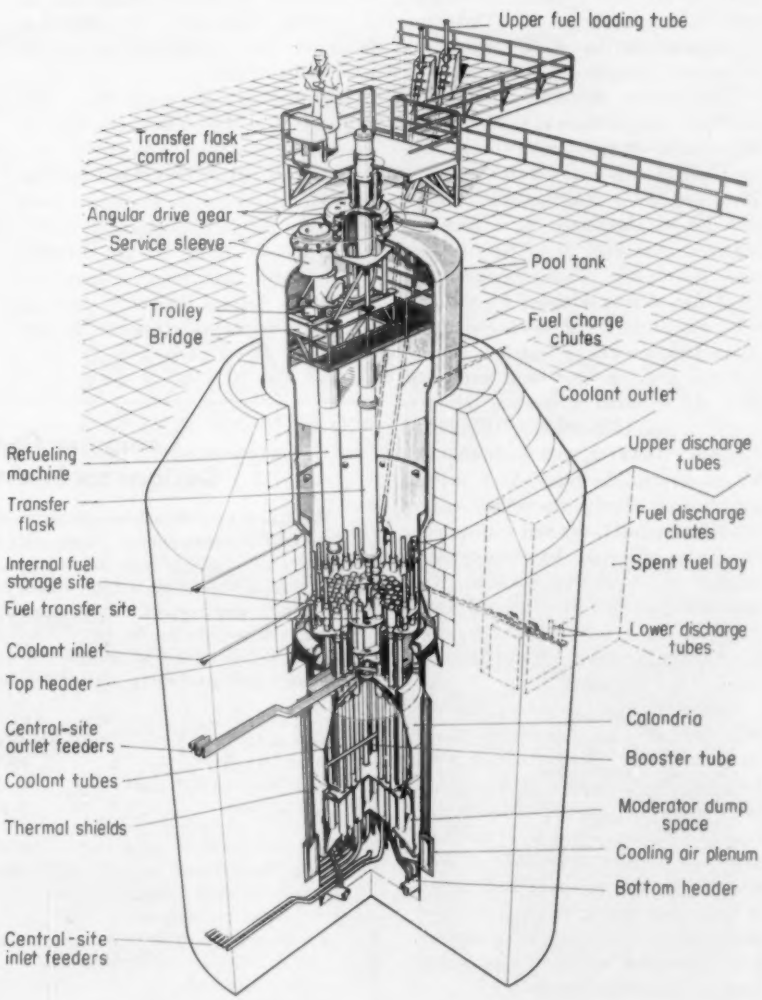
Organic-Cooled Deuterium Reactor Experiment

FIG. 1. In this 35.1-Mw(th) reactor experiment power and cost are kept low while central fuel bundles generate power density close to that of large power reactor; six central fuel-test channels have 1.4%-enriched UO_2 but outer 54 channels contain natural UO_2. Each test channel is monitored for flow, temperature and radioactivity and can be cooled in individual loop. Outer fuel bundles can be changed (with reactor at full power) by machines within pressurized shield above reactor vessel. Fuel in six central test channels can be changed only when reactor is shut down. About 100 lb of test coolant leak into main 300,000-lb system when a bundle is changed, but no reverse leakage takes place.

As with the NPD-2 and NRX reactors, control is by moderator level and temperature—no control or scram rods are required. We estimate the moderator temperature coefficient with fresh fuel is −0.07 milli-k/° F. With equilibrium fuel (2,500 Mwd/tonne U) this becomes −0.06 milli-k/° F. With a probable moderator temperature range from 120 to 180° F, this gives a range of −4.2 milli-k with new fuel.

Shield pool above core contains enough coolant to flood the reactor vessel in case of a major failure. Rupture of a coolant tube in the reactor would allow coolant to mix with D_2O, which would shut down the reactor even if all controls fail.

In operation, the Santowax-OM70 coolant keeps cladding temperature below 858° F. Maximum thermal-neutron flux is 1.87×10^{14}. Of the total 62,800-lb D_2O inventory, 48,500 lb is in calandria, which is ¼-in. 304ss 9 ft high by 11 ft in diameter. Heat is dissipated to atmosphere and there are no special irradiation facilities.



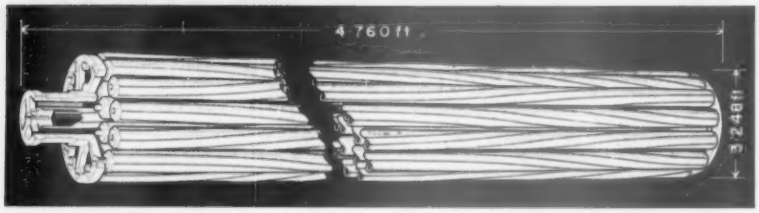


FIG. 2. OCDRE FUEL BUNDLE design has 22 Type-M257 sintered-aluminum-powder tubes (all have 20-mil wall but there are three different diameters) containing sintered and ground UO_2 pellets. Bundle is half core height; each bundle is irradiated in both top and bottom locations to obtain higher, more uniform burnup

penalty for the extra coolant exceeding 0.4 mills/kwh in a 100-Mwe plant. Thus OCDR fuel development need not start with a completely new type of fuel but rather with fuel generally similar to that being developed for NPD-2 and CANDU [see article by Mooradian and Robertson on p. 64]. Optimum burnups of more than 8,000 Mwd/tonne of natural uranium are probable.

The present reference design for OCDRE fuel bundles is in fact generally similar to those we've developed for Canada's all-heavy-water reactors. However, the organic coolant permits the use of aluminum as a cladding material (see Fig. 2). The fuel element shown here is not necessarily the type that will be adopted for the first core, but no fuel with lower reactivity characteristics will be tested.

Some concern has been expressed that the 0.040-in. clearance between fuel elements is insufficient to prevent fouling. However, we believe that the lowest cost will be reached by putting considerable effort into avoiding fouling conditions at all times and maintaining clearances dictated by heat-transfer requirements without fouling. It is interesting to note that an increase of 0.010 in. in this clearance increases power cost by about 0.1 mill/kwh in a large power reactor.

Fuel cladding. Our early assumption that sintered aluminum powder materials ("SAP" or "APM") would be first choice for fuel cladding have been borne out by the elimination of beryllium, magnesium and zirconium alloys as possible alternatives. Magnesium alloys were eliminated because of their poor strength at high temperatures and sensitivity to corrosive attack from traces of water in the organic. Zirconium alloys appear to be subject to attack from free hydrogen resulting from radiolytic decomposition in the organic at coolant operating temperatures, but their use may be practicable for thermally insulated coolant tubes operating below about 300° F. Beryllium is still a possibility, but while it has good neutron economy, its disadvantages are about the same with organic coolants as with the gas-cooled reactors for which it is being seriously considered—it is costly and difficult to fabricate, and irradiation drastically reduces its ductility.

Developments favoring SAP have occurred in at least four areas. In the first place, materials now can be produced with better and more uniform mechanical properties than two years ago. For instance, ductility at 900° F has doubled. Some of the previous erratic performance seems to have been caused by ferrous impurity particles that caused internal stresses. Hydrogen content originally was excessive and caused blistering of the metal at high temperatures. The process now is controlled rigidly and hydrogen content is at a low level.

A second major development is that AECL has shown that prolonged irradiation (1.5×10^{20} n/cm²) has no significant effect on the physical properties of this material.

Thirdly, although by no means all the problems of tubing manufacture have been solved, tubing has been produced to suitable tolerances in the desired sizes (~¾ in. dia by 0.020 in. wall). Prospective demands for quantities of this material for nonnuclear use probably will spur suppliers to greater efforts.

Lastly, good progress has been made in joining SAP, which cannot be welded by ordinary means. Pressure bonding has been performed successfully both with and without an intermediate diffusion layer of another metal.

BIBLIOGRAPHY

1. M. J. McNelly. A heavy-water-moderated power reactor employing an organic coolant, in "International Conference on the Peaceful Uses of Atomic Energy," vol. 9, p. 79 (United Nations, New York, 1958)
2. C. Grove-Palmer, H. Pass, AERE-R-3111 (1960)
3. W. E. Parkins, NAA-SR-5287 (1960)
4. NAA-SR-3575 (1959)

Computer Optimizes OCDR Designs for Minimum Power Costs

We use a very extensive computer program to optimize the design of complete OCDR power plants. Input data are based on actual costs of the NPD-2 power plant together with the most accurate estimates available of the effect of changing size, area, weight, steam pressure, etc. on the cost of each major component and system. The output gives such data as reactor lattice dimensions, steam-cycle pressures, efficiencies and fuel burnup, all optimized with respect to the net cost of energy. The following data indicate the information available and give some idea of the dependency of energy costs on the size of unit.

Power capacity →	100 Mw(e)	200 Mw(e)	300 Mw(e)
Capital cost ($10⁶)	39	58	75
Fuel and operating* costs (mills/kwh)	2.9	2.1	1.8

We can estimate total energy costs for a given location by applying the appropriate write-off rate to capital cost, which includes such items as interest during construction, engineering, the capitalized portion of the first fuel charge and the cost of heavy water.

For example, in a large publicly owned Canadian utility, a unit having a net output of 188 Mw(e), operating at 80% load factor and optimized for a conservative coolant outlet temperature of 700° F would generate electrical power costing 5.15 mills/kwh.

* Operating costs include makeup for coolant and moderator.

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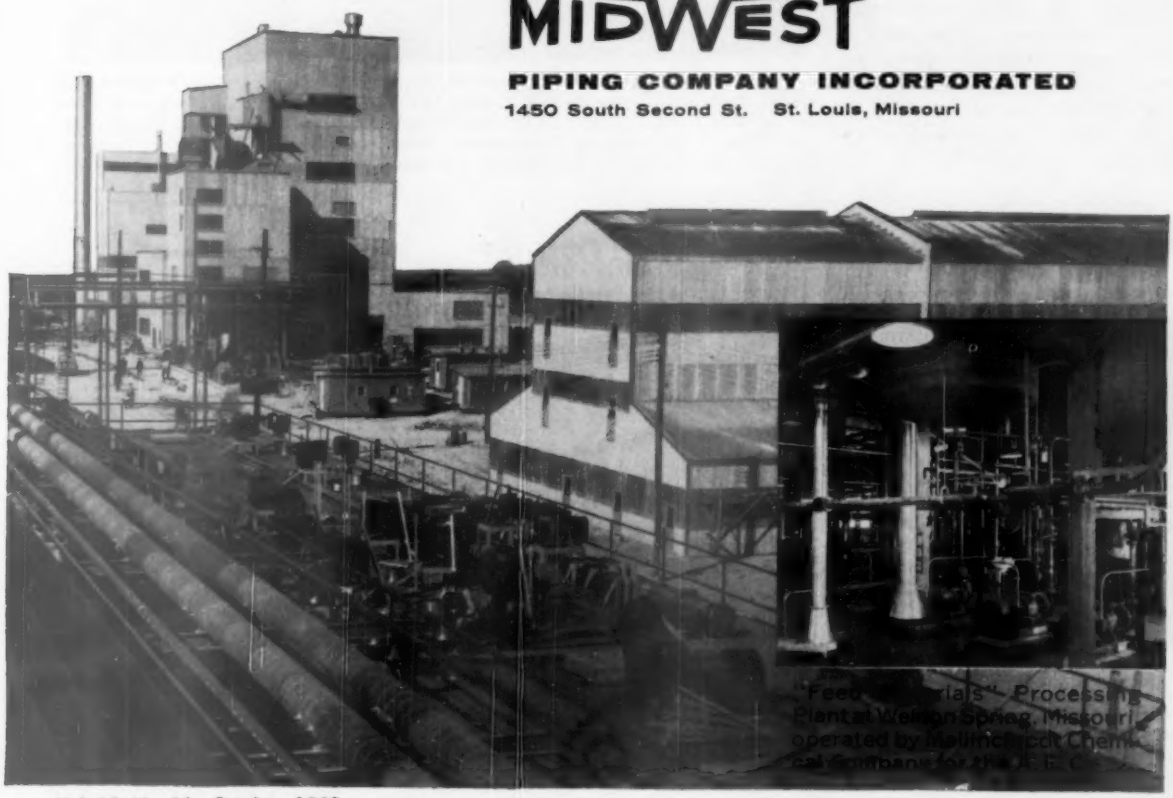

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INSTRUMENTATION and MEASUREMENTS

Versatile Data Displays for Reactors

By C. G. LENNOX and A. PEARSON, *Atomic Energy of Canada, Ltd., Chalk River, Ontario, Canada*

The size and complexity of modern reactors demand, and modern data-processing techniques make possible, a new order of data presentation for the reactor operator. He wants to be able to measure many variables continuously, store the results, and have them available as required, in any of several easily interpreted display modes. Such display schemes need to be much more revealing of a reactor's behavior than are the meters and strip-chart recorders that are the hallmarks of today's technology. The importance of more effective data display can be appreciated if you recall the scene in a typical reactor control room when, after some upset in the system, a dozen recorder charts are unrolled while operators attempt to correlate past occurrences.

Our concern about data displays for nuclear reactors had such a beginning, but the problem is much broader than that. We believe that by choosing appropriate data storage and by giving thought to the amount of reactor history that must be kept not only can the task of "looking back" be simplified but a new tool becomes available to aid the operator in assessing plant conditions.

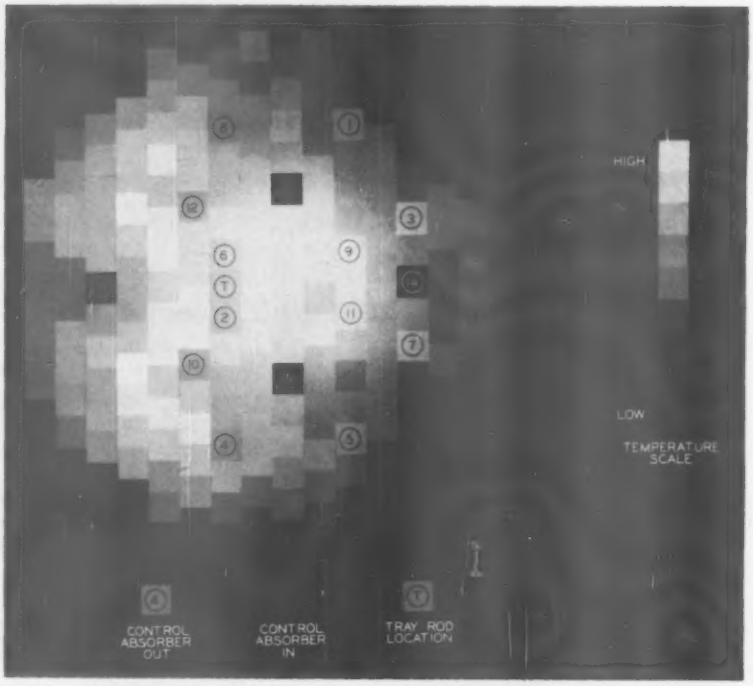

FIG. 1. TEMPERATURE MAP of tomorrow, simulated here, indicates by brightness of square cells in cathode-ray-tube display how hot corresponding fuel elements are. Stored data can be "rerun" on this display, permitting operator to "see" evolution of condition that may have shut down reactor. Modern techniques permit electronic writing of words and numbers as shown here or such fixed data could be permanently inscribed

Strip-Chart Recorder Goes Electronic, Learns New Tricks

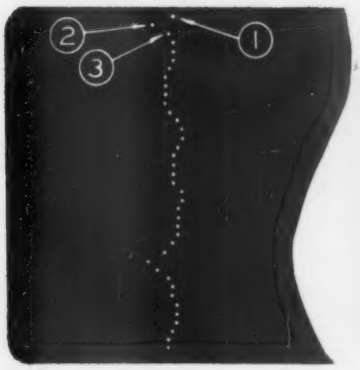

FIG. 2A. MULTIPLE-TRACE display is like multi-pen chart recorder, but traces (dots of light on cathode-ray-tube face) move as shown by arrow

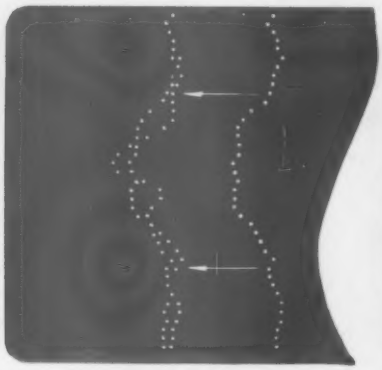

FIG. 2B. TRACES COMPARED. Electronic nature of CRT display makes it easy to shift one trace so that it is superimposed on another for direct comparisons

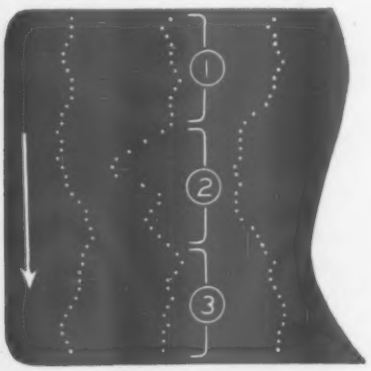

FIG. 2C. TIME IS COMPRESSED. By averaging over points in periods 1, 2, and 3 of A, display of long-term data is possible. Trace moves more slowly, of course

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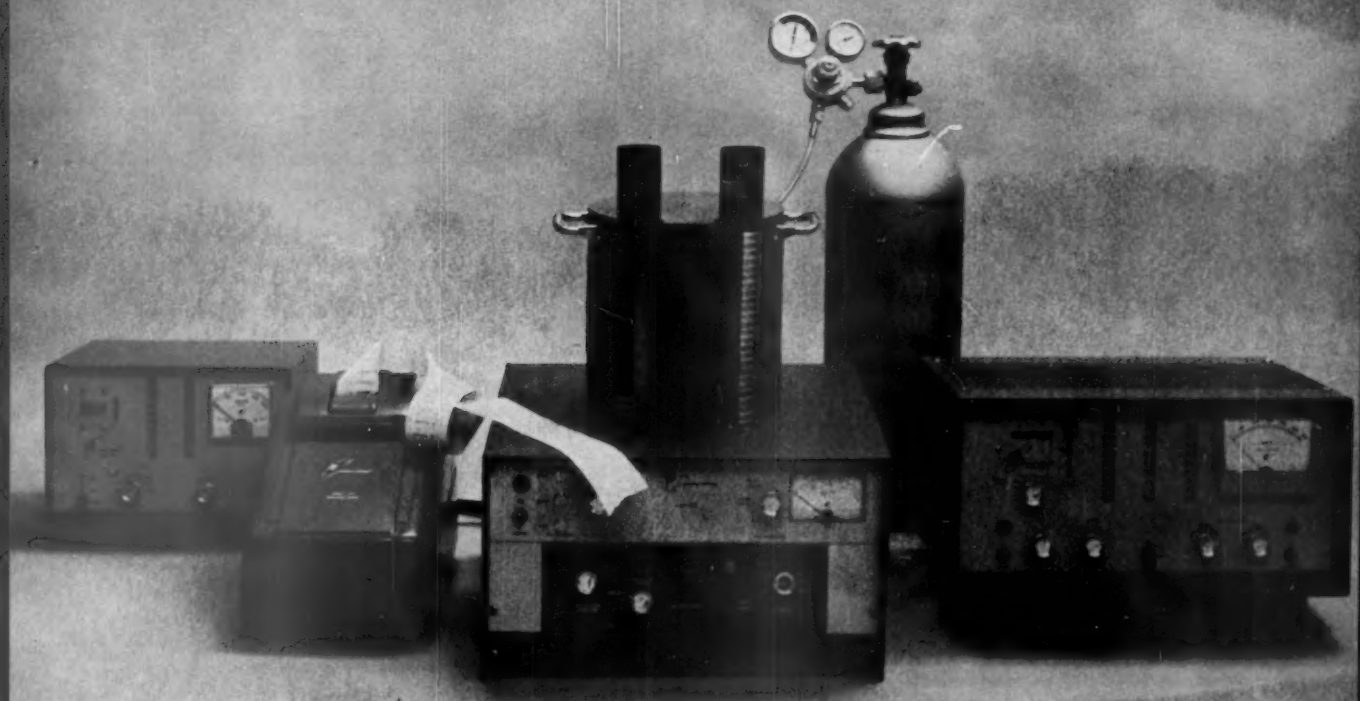

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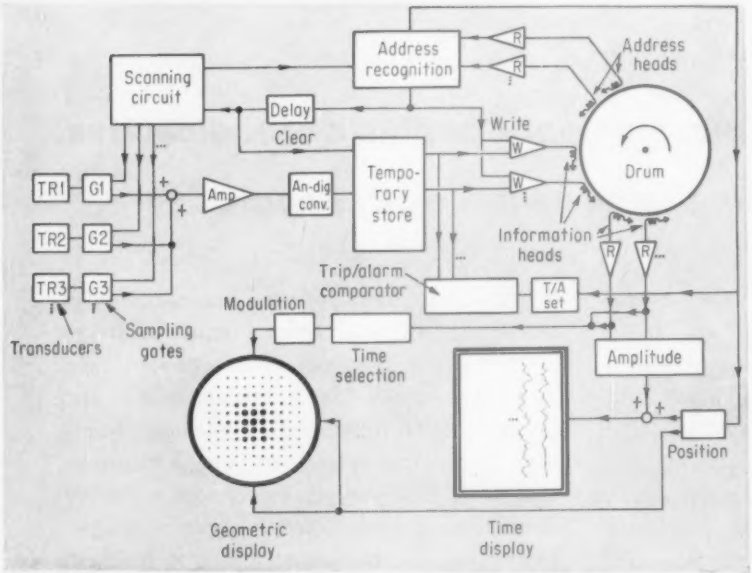

FIG. 3. HERE'S HOW it's done: Scanning circuit samples transducers in turn, sampled output is amplified, converted to digital form and stored temporarily awaiting transfer to appropriate proper position (address) on magnetic drum after address has been written. Signals on drum are read out by heads shown at bottom of drum, amplified, and displayed strip-chart fashion (as Fig. 2) or on special geometric display (as in Fig. 1)

With routine reactor operation being made more fully automatic it becomes ever more important to be able to inform the operator in charge quickly when his human intellect is required. A smoothly running plant, for which we are all striving, is not conducive to keeping people alert to reactor conditions and some means for quick retrospective appraisal is required. Therefore, our concern is not only with an adequate display of the instantaneous picture but also with supplying a picture of how the reactor reached any particular state.

When information is stored on a moving chart the display is predetermined and any other type of display such as a temperature-contour map of the reactor must be laboriously compiled by piecing together information from various charts. If, however, a rapid-access store that is independent of any display can be made feasible, then electronic means can be used to search the store and display the data in any of several forms (see Fig. 1 for an example).

Display Recent Information

If every bit of information were to be kept as long as conventional strip-chart records are normally retained no practical rapid-access store would be large enough. However, we must realize that as information ages it becomes less useful for the immediate problem of running the reactor.

With this in mind we set the criterion that only the 100 most recent measurements of a variable will be retained—each new measurement replaces the oldest. The storage requirement for 1,000 variables each measured to within 1% is then about 10^6 bits.

The 10^6 figure is obtained as follows:

$$\underbrace{100}_{\text{no. of readings}} \times \underbrace{1{,}000}_{\text{no. of variables}} \times \underbrace{(4+4)}_{\substack{\text{Binary coded decimal,}\\ \text{units and tens for 1\% accuracy.}}} = 8 \cdot 10^5, \text{ add parity check and clock pulse} = 10^6$$

This number of bits is readily stored on a 10 in. by 10 in. magnetic drum, which at present appears to be the most feasible device with both the required capacity and short access time. Longer-term trends will be recorded by storing a condensed version of the sampled information, but again the total number of stored measurements per variable will be limited to 100.

Since information collected immediately before and after a fault condition can be of importance at a much later date an entry into a permanent store is worthwhile. This may be especially desirable when a variable is being sampled rapidly and there is not time to investigate a transient before it is lost in the averaging process. In this case the information will be cleared from the drum and stored shortly after the transient occurs so that the approach to it can be seen. This process could be initiated whenever the reactor tripped or whenever a variable exceeded a preset limit. Many techniques for clearing a drum to a permanent store exist and are standard in modern data-processing systems.

Current Investigations

Two display systems are being examined in conjunction with an experimental 32-point system. The first display is based on the familiar strip-chart-recorder technique. Here the pens are replaced by electronic guns and the presentation made on the screen of a cathode-ray-tube. This is simulated in Fig. 2.

With the information in electronic form many techniques can be utilized to help the operator quickly survey the situation. Figure 2*A* shows a number of traces appearing together for easy correlation and moving in time down the face of the screen. To increase clarity half the points have been left off each trace. Example *B* shows a trace moved across the screen for more detailed comparison with another. As a further aid the amplitude of these two traces could be readily amplified to fill the screen. Example *C* reflects the transition from detailed information to the longer-term display. The information on the middle trace in *A* is shown subdivided into blocks from each of which an average is formed as shown in *C*. The resulting trace will move much more slowly than the detailed information.

Secondly, a geometric display can be synthesized very simply from the data recorded on the drum. Fig. 1 showed how this might look. The figure was made up from a temperature distribution typically found in the NRU reactor. Each cell represents a fuel-rod location. To generate this pattern the data will be read out of the drum as each address (location) is recognized and the brilliance of the appropriate area on the screen will be made proportional to the amplitude of the measurement.

(*Continued on page 132*)

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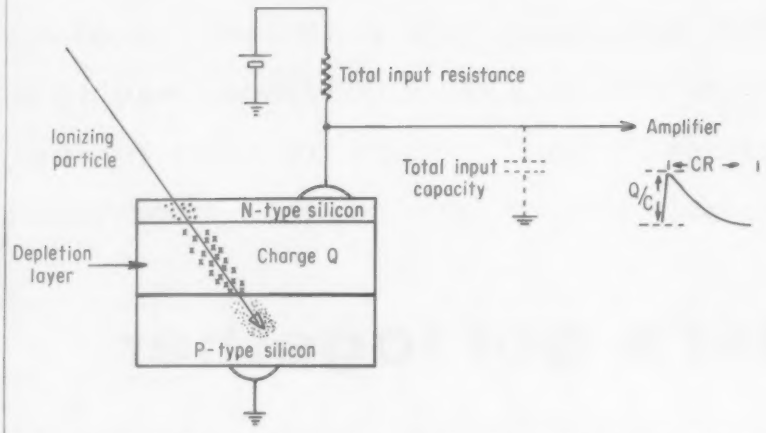

FIG. 1. OPERATION of semiconductor-junction detector. Charged particle passing through silicon detector creates electron-hole pairs in its wake; pairs formed in charge-depleted layer of reverse-biased junction create charge applied to detector capacity. The voltage pulse rises in $\sim 10^{-9}$ sec and decays with time constant of circuit. Ideally, detector capacity should be as small as possible, and depletion layer should be thick to obtain maximum charge

Uses of Semiconductor Detectors in Health-Physics Monitoring

By A. R. JONES
Biology and Health Physics Div., Atomic Energy of Canada Ltd. Chalk River, Ontario, Canada

Semiconductor detectors (*1*) offer the health physicist a number of advantages: The detecting medium is very dense compared with a gas, and the energy expended per ion pair is very low (3.6 electron volts in silicon); unlike photomultiplier and counter tubes, they operate from simple power supplies; they are rugged and have short response times. The junction mode of operation is illustrated in Fig. 1.

Alpha Particles

The simplest application is to alpha-contamination monitoring, since alpha particles are both energetic and easily stopped.

A useful monitor should have a large sensitive area (10 cm² or greater) and requires large-area junctions with low unit capacity. A monitor using a four-junction array is under development at Chalk River to survey a 16-cm² area. The total capacity of these junctions is 1,000 $\mu\mu$f and the alpha-produced pulses are up to 200 μv high. These can be amplified by a low-impedance transistor amplifier, such as the one illustrated in Fig. 2.

A monitor of this kind should have several advantages over a scintillation detector having the same sensitive area. The over-all size, weight and cost would be much reduced, and a more rugged and reliable instrument should result.

Beta and Gamma Rays

To measure beta and gamma rays, detectors with the thickest depletion layers are needed—in both cases, ionization is caused by electrons that require $\sim$1 mm of silicon to stop them. Also the electron energies are often small ($\sim$100 kev) compared with alpha-particle energies, so that to achieve a good signal-to-noise ratio, the capacity

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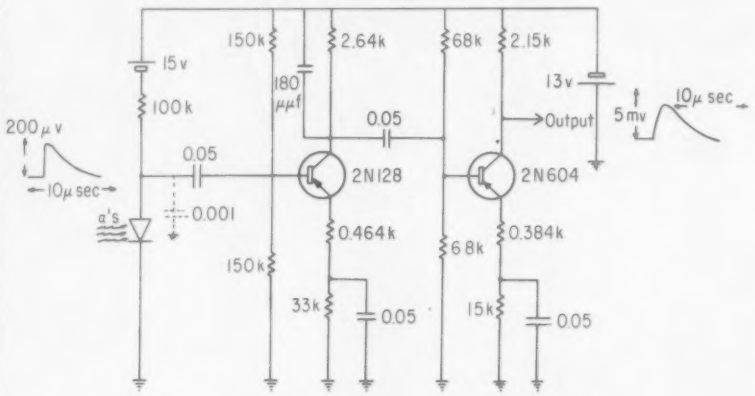

FIG. 2. INPUT CIRCUIT for large-area alpha detector

of detector and amplifier must be small. For these reasons, small-area junctions with thick depletion layers are needed.

At Chalk River, such counters (with capacities ~1 μμf) have been made using high-purity silicon (*2*). To avoid reducing the signal, an amplifier with low input capacity (see Fig. 3) is needed.

The efficiency of gamma-ray and beta-particle detection is limited by the physical size of the detector. A counter made of very pure silicon would yield the largest detecting volume for a given capacity.

The possibility of using junction detectors in a gamma dose-rate meter is being investigated at Chalk River because such a monitor might be smaller and more reliable than existing types. To make such an instrument work over a wide range of photon energies, the detector response over the energy range must first be measured. A typical pulse-height spectrum is shown in Fig. 4; note that it is continuous from zero up to a maximum value. This maximum pulse height is a function of detector dimensions and photon energy. Thus the total number of pulses and their sizes vary with energy. Since

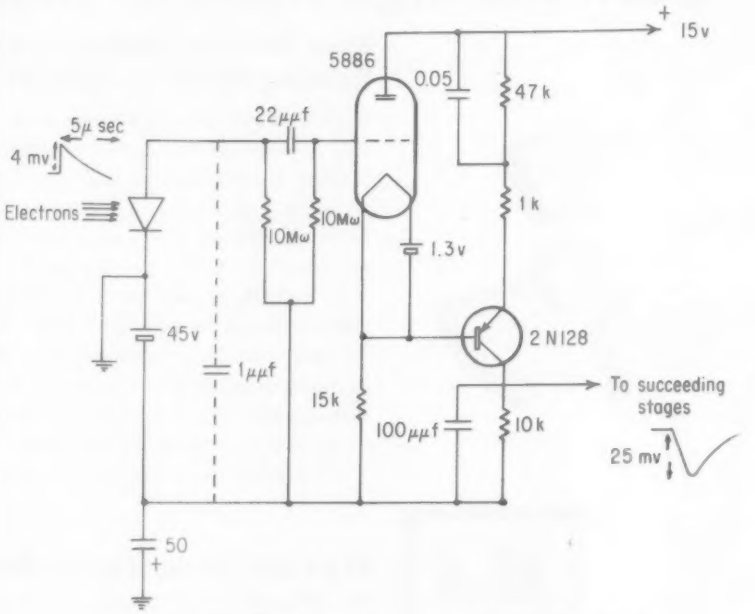

FIG. 3. INPUT CIRCUIT for small-area γ-and β-radiation detector

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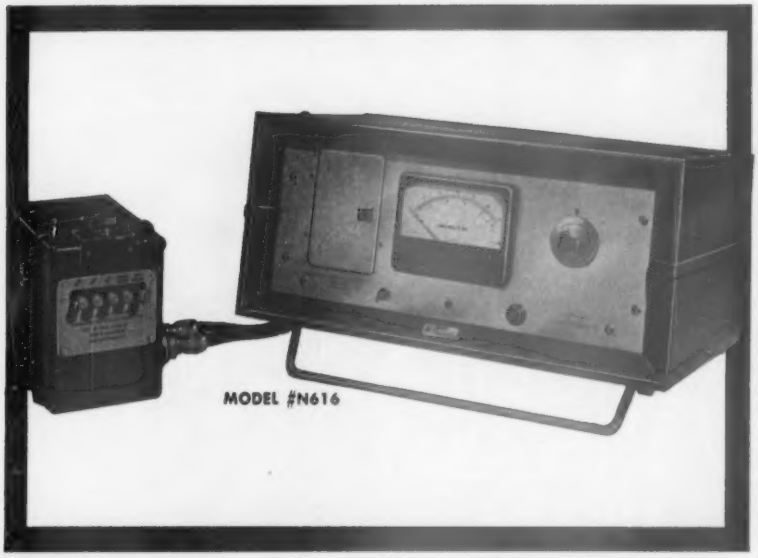

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most ionizing electrons originate outside the depletion layer, some control over counter response is possible by the correct choice of surrounding medium.

The pulses produced by gamma irradiation can be handled in two ways: (1) all pulses between certain size limits can be counted; (2) both size and number of pulses can be taken into account. The first alternative is simpler if it can be made to work. It requires that even low-energy photons produce some pulses large enough to be counted.

To take account of pulse size as well as number, the pulses can be amplified and then rectified or the radiation-induced direct current can be amplified. The a-c method is difficult if a wide range of intensities is to be handled, and the d-c method is limited to intensities where the signal current is not small compared with the detector-leakage current. It is interesting that an alpha detector 2 cm² in area has about the same d-c sensitivity to gamma radiation as a 300-cm² air ion chamber.

Neutrons

Because alpha particles, protons and fission fragments are directly detectable, neutrons can be detected by means of neutron-sensitive coatings.

Fission fragments coming from a U^{235} layer in front of a junction provide one means of neutron detection. Unfortunately, a uranium layer having a thickness equal to the fragment range

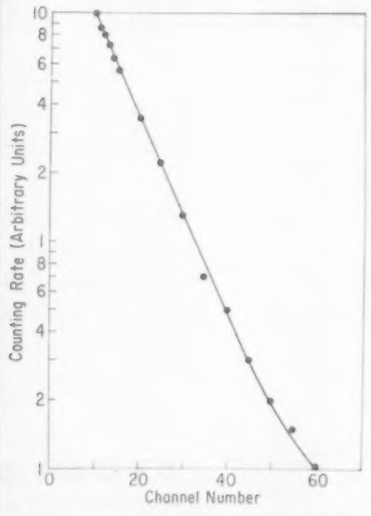

FIG. 4. TYPICAL PULSE SPECTRUM of high-impedance semiconductor detector under radium gamma irradiation

provides only a small cross section. There is also the danger of radiation damage because of fragment mass and energy.

More promising is the boron-10 (n, α) lithium-7 reaction, which provides a 1.47-Mev alpha particle of sufficient

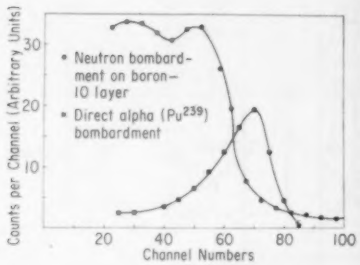

FIG. 5. NEUTRON SPECTRUM obtained with B^{10}-coated, large-area junction compared with Pu^{239}-alpha spectrum obtained with same detector before boron coating; channel numbers correspond to different energy scales for the spectra. Difference in spectral shapes arises because boron layer behaves similarly to thick alpha source

penetration. Figure 5 shows the pulse-height distribution obtained from a large-area junction coated with B^{10} when bombarded with neutrons from a plutonium-beryllium source.

Needed Developments

At the present time, both alpha and neutron monitors using junction detectors are feasible and offer similar advantages. Gamma and beta monitors must await more detailed study of existing detector types or further developments of them. One welcome development would be a detector that itself amplifies, because the electron-produced pulses are often inconveniently small. Such a device, now under study, is a transistor detector that provides current gain (*3*). Another possibility is a diode that can be triggered into an avalanche mode by radiation—the solid-state equivalent of a G-M tube.

Higher-purity silicon is needed for all junction applications in health physics, providing thicker depletion layers and smaller capacities. Improvement in pulse size and in detection efficiency could then be attained.

BIBLIOGRAPHY

1. S. S. Friedland, J. W. Mayer, J. S. Wiggins, NUCLEONICS **16**, No. 2, 54 (1960)
2. J. M. McKensie, J. B. Waugh, *Trans. Professional Group on Nuclear Science—IRE* **7**, No. 2 (1960)
3. R. L. Williams, *Bull. Am. Phys. Soc.* (2)**5**, No. 5, 354 (1960)

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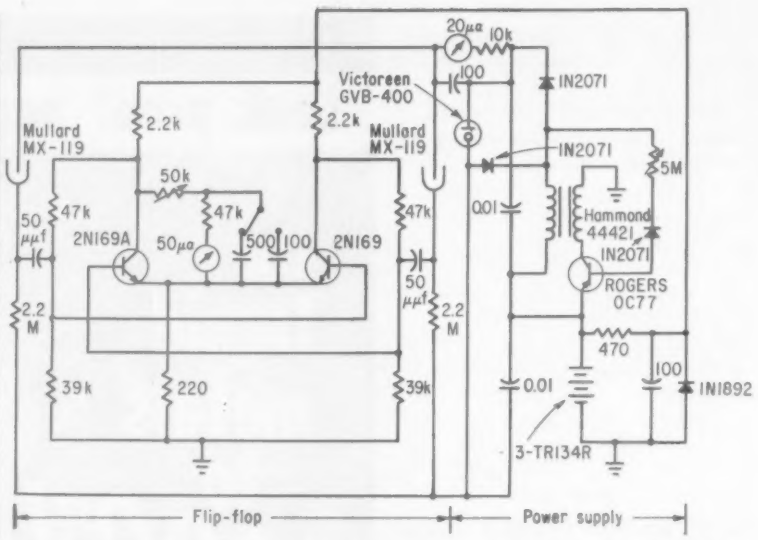


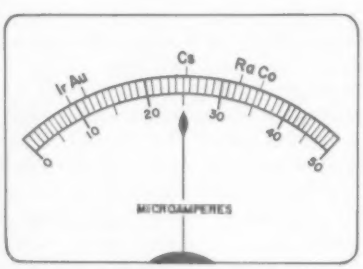
RATIO CIRCUIT. 50-μamp meter across left-hand transistor of two-transistor flip-flo indicates fraction of time spent waiting for pulse from unshielded right-hand G-M tube (Mullard MX-119) after circuit has been switched by pulse from shielded left-hand tube

Dual Detectors Key to Radioisotope Identifier

By R. W. TOLMIE, *Commercial Products Div.*
Atomic Energy of Canada Ltd., Ottawa, Ontario, Canada

Gamma-ray energy, and hence the emitting radioisotope, can be readily measured with the circuit shown. Ratio of counting rates from twin 7-cm × 1-cm halogen-quenched G-M tubes mounted together in probe provides the essential measurement. One G-M tube is shielded by 1 cm of lead, the other is not. Idea is that absorption in shield (and hence relative counting rates) depends on gamma-ray energy. Radioisotope can be read directly on face of meter as shown in inset.

Detectors are connected to opposite sides of transistor flip-flop circuit. Proportion of time either half is conducting depends on ratio of counting rates and is measured by metering average voltage across transistor in opposite side of flip-flop. Zener diode regulates flip-flop supply voltage. Longer time constant is used for meter when counting rate is low or a steady meter reading is required for maximum resolution. With this time constant and using Mullard MX-119 Geiger tubes, the identifier will operate in fields from about 1 mr/hr to 40 mr/hr. Upper limit is set by disproportionate dead-time losses, lower limit by meter fluctuations and fact that background radiation determines effective energy. 20-μamp meter in series with high-voltage supply indicates when field is within proper limits. Power supply has simple oscillator that drives miniature transformer; high-voltage output is rectified, filtered and shunt-regulated using a corona regulator tube.



METER READS ISOTOPE. Face of 50-μamp meter is marked at characteristic readings. Higher gamma energy gives higher current

Photographs courtesy Sylvania-Corning Nuclear Corp.

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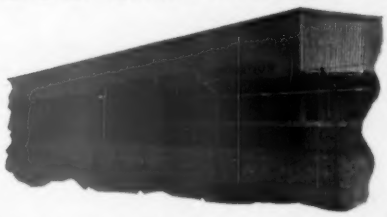

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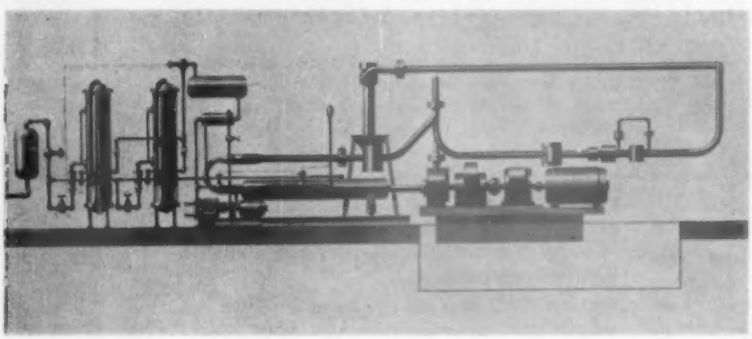
Technician makes rolled-joint seal between pressure tube and end fitting in program to develop this technique for Canada's pressure tube-reactors. Tube expander inserted inside tube end exerts mechanical pressure through rolling action that forces tube surface into tight contact with end fitting. Rolled joints have been consistently leak-tight and with strengths greater than the tube strength at 530° F. Joints can be made remotely to replace pressure tubes in a reactor.

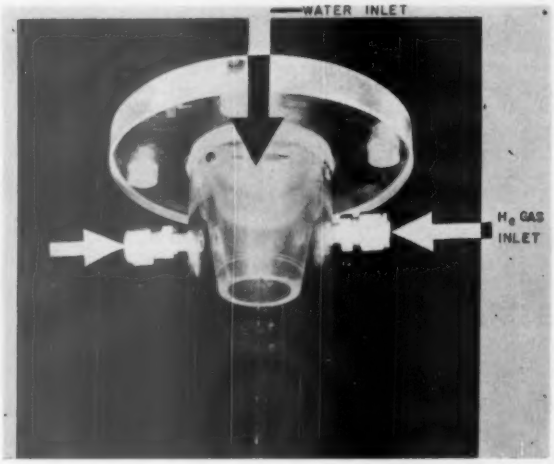
Orenda Works with Superheated Steam, Anodic Films

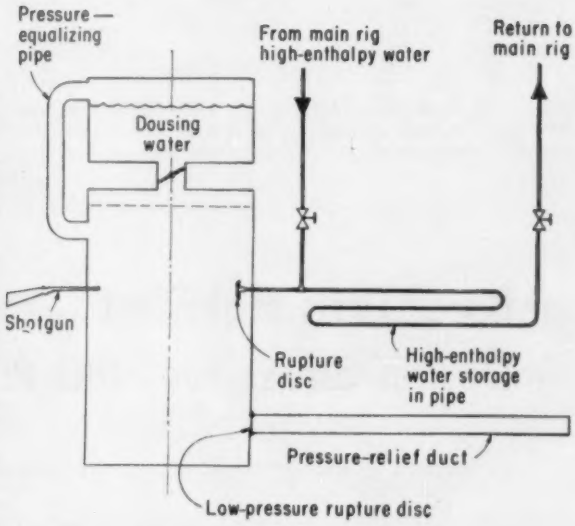


Novel out-of-pile loop (above) has a test section (vertical tube at center) cooled by superheated steam at 1,500 psi and 1,050° F. D-c electric heating simulates up to 560 kw of fission heating in fuel specimens. The centrifugal compressor, right, (1,000°-F, 1,500-psi inlet conditions) can circulate as much as 20 lb/sec through the test section. The heat generated is removed by continuously blowing-off steam. Horizontal tank at center is desuperheater while tanks at left are water-treatment system.

Anodic oxidation of Zircaloy-2. A correlation between the effects on Zircaloy-2 of anodic oxidation in acid media and exposure in a steam autoclave may lead to extensive use of the former for determining corrosion resistance of Zircaloy-2 in high-temperature water. The advantage would be that the anodic method could be carried out in a much shorter time than the three days required for the autoclave test. Orenda has developed methods to determine to within 10% the thickness of anodic films produced on Zircaloy exposed to a sulphuric-acid-nitric-acid-water system. Orenda then plans to correlate anodic film thickness with corrosion measure in autoclave tests. The films also promise to be of interest in themselves as a protective coating for Zircaloy-2.

With Test Loops



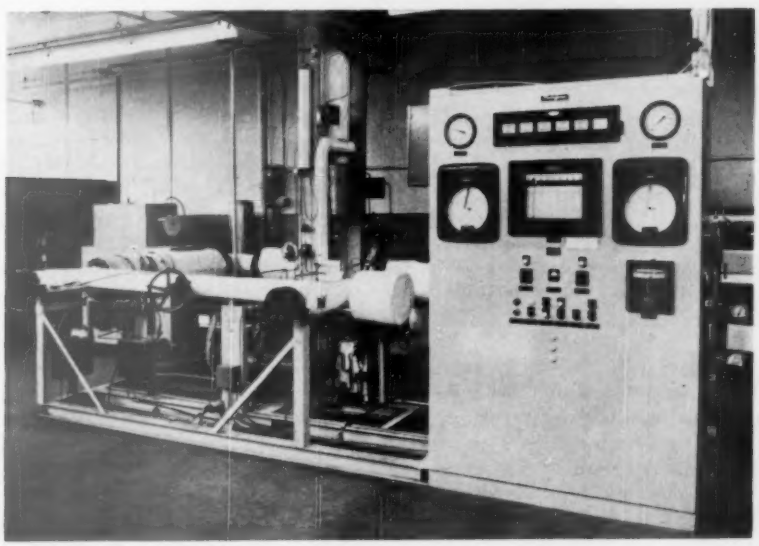


Water Pumps Helium Gas, Condenses Steam at AECL-NPPD

Hydraulic helium compressor works by entraining gas in a downward-moving column of water. Entrained gas is compressed by the increase in hydraulic head with decrease in height of moving water. AECL's Nuclear Power Plant Division is developing a design to provide the 5-psig He pressure difference needed for moderator-level control for NPD and CANDU reactors. New pump promises to be cheaper and more reliable; main problem is getting a large enough air-to-water volume ratio.

Test facility mocks up containment system for NPD and CANDU reactors. Shotgun blast ruptures the disc in high-enthalpy water system, simulating rupture of primary-coolant circuit. Initial discharge of water-steam mixture is vented to the atmosphere through relief duct at the bottom. At later stages in the discharge the pressure controlled butterfly valve releases a cold-water spray that condenses the escaping steam. Test tank is 17 ft high and 7 ft in diam.

Canadian Westinghouse Builds Test Loops



Reactor Component Test Loop (left) subjects specimens to thermal and pressure cycles, can go from 100° F to 600° F at 5°/min and from 0 psig to 2,000 psig at 70 psi/min. Less photogenic but more ambitious is a 275-kw gas-cooled loop designed and now completing fabrication by Canadian Westinghouse. The loop, now partially installed in the WTR, will be cooled by 32,000 lb/hr of CO_2 at 500 psig and a maximum temperature of 860° F. The loop was built for General Nuclear Engineering Corp. who will use it to perform tests in support of its D_2O-moderated, gas-cooled pressure-tube reactor. Even with a 860° F gas temperature, thermal insulation holds the outside surface of the test section (in contact with the water) to about 150° F.

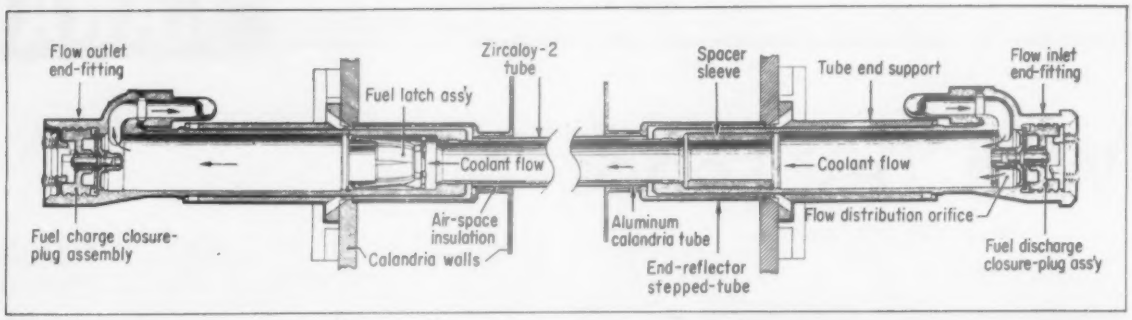


FIG. 1. NPD PRESSURE-TUBE assembly consists of straight, uniform Zircaloy-2 tube passing through reactor core and complex type-410 stainless-steel end fittings outside high neutron flux. Each pressure tube supports fuel assemblies horizontally, provides passageway for D_2O coolant heated by fuel and permits reloading fuel elements independently of other channels at full power

Burst Tests Help Set Design Stress for NPD Pressure Tubes

By WILLIAM A. WOLFE,* *Atomic Energy of Canada Ltd., Chalk River, Ontario, Canada*

Pressure tubes are basic features of both the Nuclear Power Demonstration Reactor (NPD) and the Canadian Deuterium Uranium Reactor (CANDU). Because of the high operating pressures and temperatures (about 1,050 psig and 530° F for NPD), the pressure tubes must be designed carefully for the highest possible integrity. The tube design must also promise adequate resistance to corrosion and adverse radiation effects—all at minimum annual cost.

The pressure-tube designer has a double economic incentive to design the thinnest tube possible—not only is first cost important but neutron absorption by the tube material is costly. An important ingredient in setting the pressure tube thickness is the allowable design stress. For instance, calculations for the CANDU reactor show a saving of $2-million or 0.1 mill/kwh if the design stress for its tube material (Zircaloy-4) is increased from 15,000 to 18,000 psi. Thus we have made a particularly careful study of the properties of our tube materials, backed this up with realistic design and confirmed our results with both tensile and tube-burst tests.

Design Stresses

In NPD the pressure tubes will be subjected to several forces—internal pressure, gravity load due to weight of tube and contents, loads imposed by supports and thrust from feeder pipes.

As shown in Fig. 1, the complete pressure-tube assembly includes quite complex end fittings, but the tube itself is straight and uniform, which simplifies stress calculations.

In 1957, when we decided that NPD should be a pressure-tube reactor, information was available on tensile properties of Zircaloy-2 sheet and strip, but not for tubular shapes. The mechanical properties of Zircaloy-2 sheet made it apparent that we would need to use cold-worked material to obtain a suitable design stress. For example, if we cold-work 15–20% we can raise the design stress from 8,000 to 13,000 psi.

We used the ASME Boiler and Pressure Vessel Code, Section VIII (Construction of Unfired Pressure Vessels), as the basis for design. At first we assumed 41,000 psi as the minimum ultimate tensile strength for 15% cold-worked Zircaloy-2, but our tests later showed 51,000 psi to be mor realistic. We calculate thermal stresses to be about 1,200 psi, but, since the ASME Code (revised by Case No. 1234) allows a temperature stress equal to half the allowable stress before requiring that the thermal stress be considered in determining the wall thickness, we omitted these stresses from our calculations. With a tube wall of 0.156 in., the calculated maximum principal stresses are 13,750 psi at the outlet and 14,170 psi at the inlet. These stresses meet all the requirements of paragraph UA 601(a) of the Code except that the safety factor based on the lower assumed ultimate tensile strength (41,000 psi) is three instead of four. The designers and the boiler inspection branch of the Ontario Department of Labor consider this safety factor acceptable because of the simple and calculable loading plus the rigid quality control and inspection specified for each tube.

Burst Tests

The design of the pressure tubes is, we have seen, based on the minimum mechanical properties that our experience teaches us to expect. We are, however, bound to determine whether the tubes that will actually be used do

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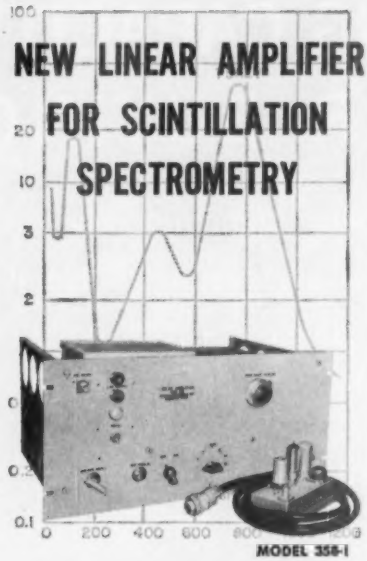

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have these properties and whether there is variation in the product of one manufacturer or between the products of different manufacturers. One way to make such a determination is to take small-size samples cut both longitudinally and transversely and subject these to tensile tests. However, this gives only limited information; the burst test (to be described below) adds confidence to our determination of mechanical properties because it subjects a sample of the tube to stresses which, though they are much larger than those to be met in service, do have the same geometrical distribution.

After all, although some experience with Zircaloy-2 in reactor conditions exists, the final proof of a pressure-tube design can come only from long-term operating experience in a reactor. Obviously, a reactor must exist for this experience to be obtained—but NPD will be our first pressure-tube reactor. So we have tried to design NPD with as much knowledge of material properties as we can obtain. The mode of fracture is an important characteristic. We have investigated it by burst tests. We plan to burst-test about 30 tubes; thus far we have tested seven.

Specimens. For the test, sections of NPD pressure tubes ~24 in. long are rolled into end fittings that duplicate the NPD tube-to-fitting joint in essence. The rolled joints are made by the same firm (Canadian General Electric Co., Ltd.) that is making the actual NPD joints; so the actual and test joints are as nearly identical as possible, although actual pressure tubes will be ~13 ft long. We measure the thickness of the tube to be burst and attach thermocouples and strain gages at suitable locations.

Test method. First we eliminate thermal stresses by bringing the entire tube to 535° F by filling it with water at that temperature. Then we increase the water pressure steadily until the tube fails. (The pressure needed to rupture the tube is at least five times the NPD pressure of 1,050 psig.)

Figure 2 shows a tube after failure. Because we use high-enthalpy water, significantly more energy is released at failure than if we used cold water. In all tests a portion of the tube between the end fittings is ejected violently. The metal ejects so violently from the apparatus that it is further deformed when it hits the walls, ceiling or floor of the test pit. However, the bursting 3.75-in.-i.d. tube must open enough to clear an internal 3-in.-dia heater tube (the annulus is at least ⅛ in.); as yet there are no marks on the heater tube to indicate that it has been struck by the ejected metal. It should be borne in mind that the high-pressure burst tests are concerned with material properties only; in the reactor the pressure is so much lower that no such burst could occur.

FIG. 2. PRESSURIZED ZIRCALOY TUBES burst when shear stresses cause axial crack to form and run axially at 45-deg angle to radial line until forced to turn (usually 90 deg) by end fitting; crack is smooth and sharp edged except for 1–2 in. where it starts. Whether crack extends to both ends depends on where it starts—sometimes when crack turns at one end, tube opens so that crack at other end goes around tube before reaching second fitting

Results. These results of the high-pressure burst test increase our confidence in Zircaloy-2 as a pressure-tube material and in the soundness of the rolled joint between the Zircaloy tube and the stainless-steel end fitting. The table compares the strength of Zircaloy-2 as obtained from burst tests and from tensile tests (we test transverse and 0.059-in.-dia by 0.275-in. Chevenard samples from the tube to check anisotropy of tensile properties). Strengths derived from the burst tests invariably are higher than those from the tensile tests. So far we have not

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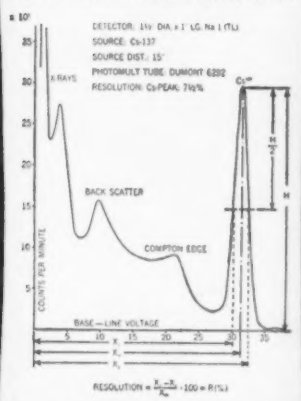

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been able to explain the exact magnitude of this discrepancy, but we feel that more is involved than the fact that the stress is applied biaxially in the burst and longitudinally in the tensile test. The method of manufacturing the tube establishes preferred orientation of the Zircaloy crystals that strengthens the tube in this application.

We have seen no failure at the rolled joint, even though we reroll and reuse some end fittings three times. The joint did not fail even in a test where we overrolled the joint to the extent that the tube beyond the fitting was visibly expanded. In every test an intact portion of the tube remains in the end fitting even though we apply no external longitudinal restraint.

Radiation Effects

We were concerned that irradiation might increase the rate or decrease the temperature at which the thermodynamically unstable 15% cold-worked Zircaloy-2 goes to the stable annealed condition. Since 1957 we have made enough direct studies at AECL* supported by basic studies elsewhere† to show that irradiation below 720° F does not increase the recovery rate of such moderately cold-worked material. At 540° F irradiation to 10^{20} n/cm² increases ultimate tensile strength 14% and yield strength 28%. Moreover, when annealed material is irradiated it hardens; so the annealed condition would never be reached by irradiation at such temperatures.

Zircaloy-2 Properties

Test	*Ultimate strength* (psi)*	*Yield point* (psi)*
Tensile	51,200–57,300	42,800–49,700
Burst	64,000–76,000	55,000–62,000

* At 530° F after autoclaving in 750° F steam for 3 days.

Corrosion

Corrosion of the Zircaloy has also been a question. To verify the integrity of the protective black oxide we autoclave each tube for four days in 570° F steam. This may represent undue concern, because we have had very satisfactory experience with a 3.136-in.-i.d. Zircaloy-2 tube of 0.692-in. wall that has been in the NRX reactor since June, 1957, in water of 520–540° F and 1,200–1,500 psig. We hold the water *p*H between 9.5 and 10, and the hydrogen content varies between 5 and 15 cm³/kg. We have examined the tube eight times and found it to be in good condition despite frequent changes of fuel (for experimental reasons) with consequent damage to the surface film. Movement of fuel assemblies has formed grooves in the tube surface, and we have seen two cases of fretting. Subsequently these regions regained their covering of black oxide. After 2½ yr the outside of the tube retains a black-oxide coating although the adjacent aluminum-alloy jacket has been corroded by the nitric acid produced by the irradiation of the surrounding air.

* E. C. W. Perryman, AECL-1048 (Chalk River, Ontario, 1960).

† M. J. Makin, A. T. Churchman, D. R. Harries, R. E. Smallman in "Second International Conference on the Peaceful Uses of Atomic Energy," vol. 5, p. 446 (United Nations, New York, 1958).

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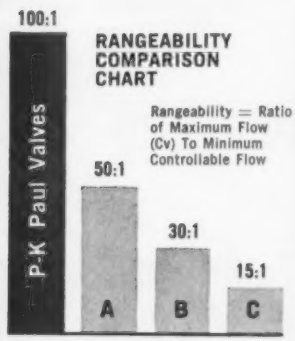
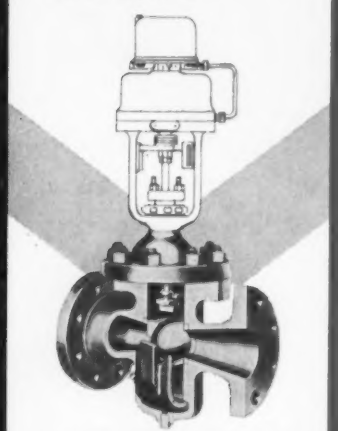


A—Globe Valves, V-Port Plug
B—Globe Valves, Contoured Plug
C—Butterfly Valves



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Spray Technique Applies Shielding Concrete

By FRANK C. HUME
B. D. Bohna & Co., Ltd., Vancouver, British Columbia

Spraying is an economical way of placing the dense magnetite concrete needed in shielding against intense radiation. This new method sprays rather than pours the concrete. The process was used for the first time with magnetite in the High Level Radiochemistry Facility at Hanford. The spray method has numerous advantages of cost and quality over conventional techniques of concrete placement for high-density applications.

Application Process

Pneumatically applied concrete is commonly given the trade name "Gunite." Compressed air traveling through a hose carries a dry cement and fine aggregate mixture to the face that is to be shielded. The dry mixture leaves the nozzle as a fine high-speed spray. At the nozzle, water is added under pressure to complete the mix. In general, the aggregate particles travel separately and not as a continuous stream between nozzle and concrete face.

Since very little published data is available on pneumatically placed concrete with magnetite aggregates, we had to start from scratch in testing this new process and choosing materials for the job. After investigating various magnetite aggregates and aggregate-cement mixtures, we settled on a fine aggregate (fineness modulus 1.75; specific gravity 4.86), the by-product of a magnetic separator that was processing dredged river sand near Boise, Idaho. Suitable material can probably also be found in wide areas of both the United States and Canada.

Advantages of Spray

The advantages of the Gunite process over either conventional pouring or prepacked methods are many. Among the most important are the following:

Lower final costs. Our construction records at Hanford show that the final costs of the pneumatically placed concrete compare favorably with firm quoted prices for both conventionally premixed placement and prepacked methods (see table). The experience we gained at Hanford will probably result in an additional 15% saving on future jobs.

Faster construction. We saved ~3 weeks of construction time by using Gunite. Since the process does not require the erection of outside forms or form stripping and removal, we could start the placement of the concrete as soon as we had checked the inserts and reinforcement. In conventional methods of placing concrete, work other than that connected with the forming or concrete placement seldom proceeds from the time of erection of forms until stripping is completed. The three weeks saved meant substantial savings in construction overhead, insurance, equipment rentals, etc. This represents $500–1,000 per

Comparative Costs for 175 Cubic Yards of High-Density Concrete

	Gunite (construction records)	*Premix and pour (quoted prices)*	*Prepacked (quoted prices)*
Forms	$2,493	$9,500	$10,500
Aggregate	18,766	20,500	
Cement	2,611	2,000	32,000
Equipment, labor and misc. supplies	14,736	8,500	
Finishing	2,026	2,000	
TOTAL	$40,632	$42,500	$42,500
Per cubic yard	$232	$242	$242

SPECIFICATIONS:

Variation in cathode luminous sensitivity over entire cathode	± 20%
Cathode luminous sensitivity	70 ua/lumen
Shock	40 g, 11 ms. duration
Vibration	10 g, 25-2,000 cycles

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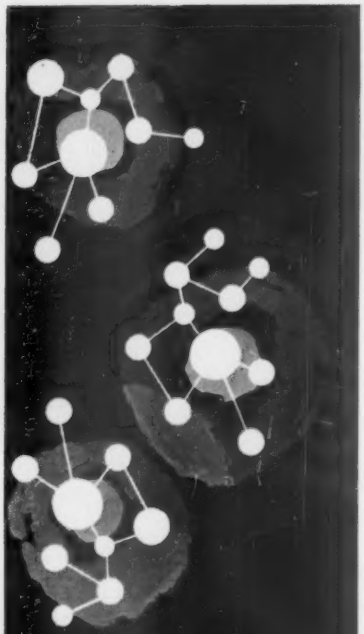

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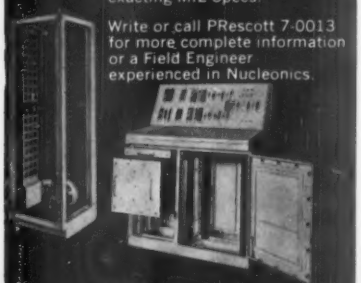

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week depending on the company and the dollar value of the job.

Work can continue on the placed concrete much more quickly than on conventionally poured materials, because the Gunite reaches 3,000-psi strength in only 7 days.

Greater density and strength. Gunite provides greater density and strength than can be achieved using conventionally placed concrete with aggregates of the same specific gravity. The U. S. AEC at Hanford ran laboratory tests using 53 standard test cylinders taken during the placement period (6-in. diameter; 12-in. length). The following representative values of compressive strength result from these tests: at 3 days, 2,154 psi; at 14 days, 4,193 psi; at 28 days, 5,180 psi. The approximate density of the concrete was 235 lb/ft³. Published data indicate that good workable mixes of magnetite aggregate and cement do not consistently produce densities as great as 220 lb/ft³ even under laboratory conditions.

Few voids. Because Gunite is applied as a very fine stream of particles, we can watch it very carefully during placement. We check each layer by prodding for consistency and check each nook and cranny before the Gunite sets. This means that we can eliminate the possibility of voids of any kind in a complicated structure or shield.

No damage to inserts. The fine Gunite spray completely removes the chance of damaging or dislocating tubes or inserts that are to be buried in the concrete. Thus, elaborate precautions to prevent dislocation of inserts become unnecessary and costs are saved.

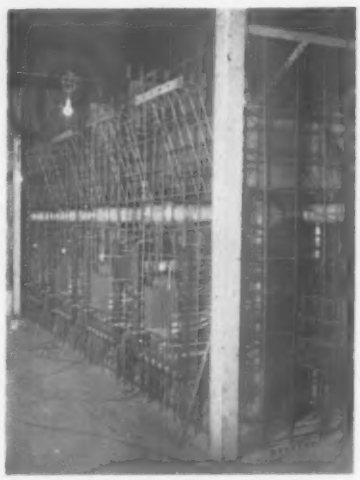
Trowel finish. A trowel finish rather than a formed finish is used in the Gunite process. This trowel finish, denser and freer of pinholes than the formed finish, is important for surfaces that must be decontaminated.

No heat problem. Heat of hydration presents no problem in heavy-wall sections. The Gunite process places concrete in thin continuous layers so that heat is generated in and dissipated from each successive layer rather than from the large mass.

* * *

These investigations were carried out by B. D. Bohna & Co., Ltd. under a design-construct contract with the U. S. Atomic Energy Commission.

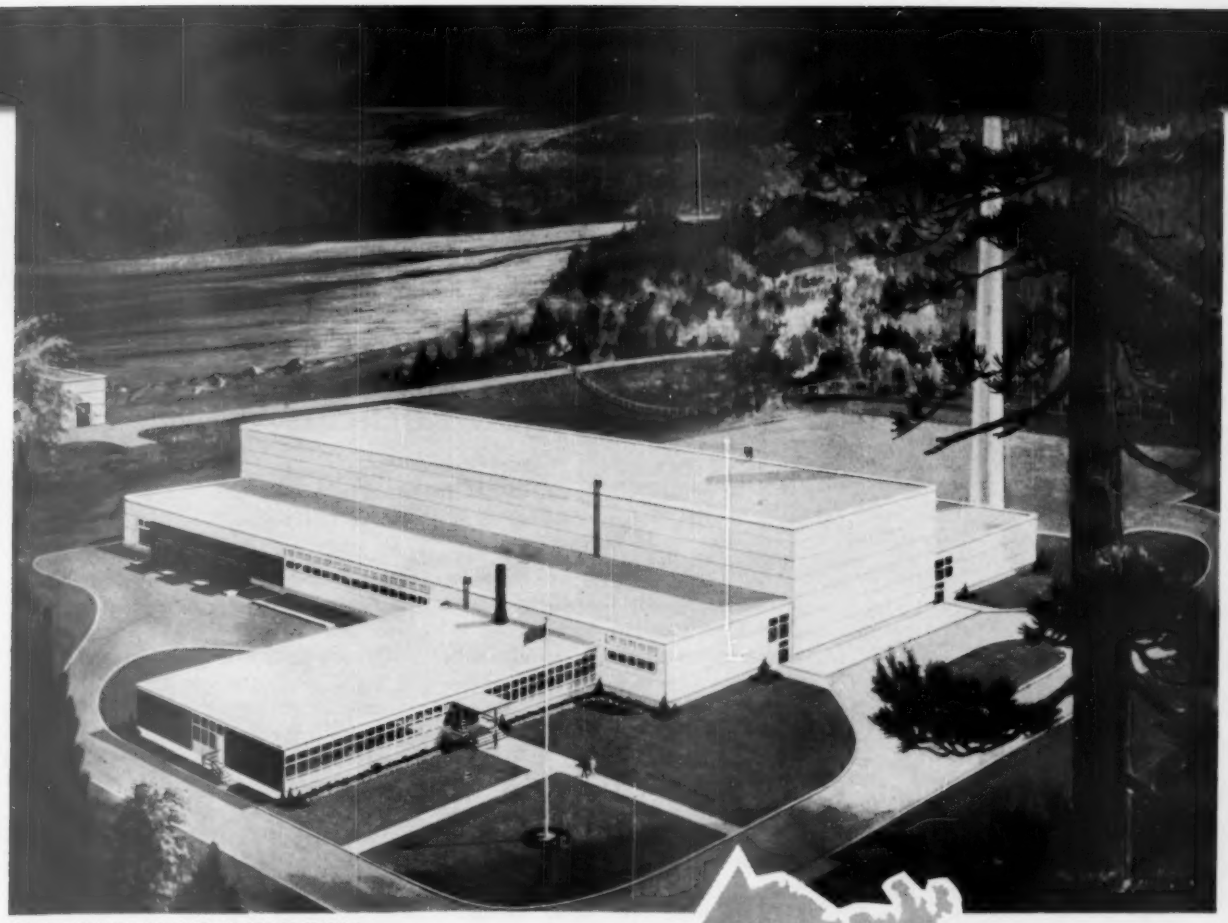
Gunite Shield—1,2,3 . . .



1. . . . READY to go; note absence of forms

2. . . . SPRAYING Gunite means few voids

3. . . . FINISH is troweled, hence smooth



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It is expected to be the forerunner of a series of large power stations which will generate electricity at costs competitive with fossil fuels in many parts of Canada.

In addition to the work on this pioneer project, CGE, under contract to Atomic Energy of Canada Limited, is currently engaged on the design and development of an organic-cooled, heavy-water-moderated reactor (OCDR), which also shows great promise of economical application for the electrical utility systems.

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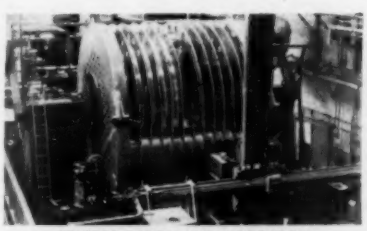

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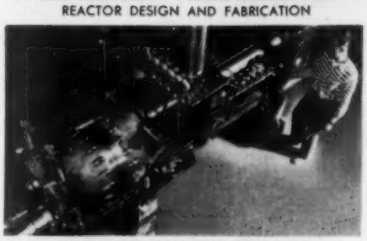

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Gaging Gas Density with Fast Charged Particles

By BERTHOLD W. SCHUMACHER
Ontario Research Foundation, Toronto, Ontario, Canada

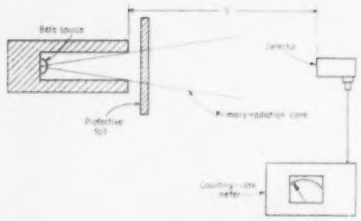

FIG. 1. ATTENUATION GAGE exhibits exponential counting-rate-density relationship over at least one decade

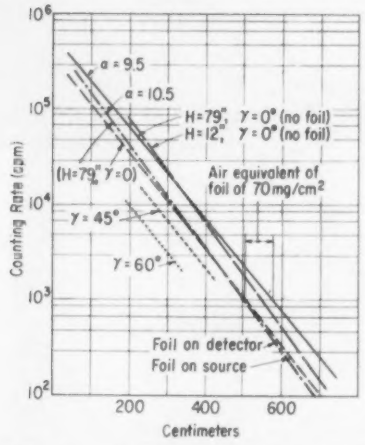

FIG. 2. Sr^{90} CALIBRATION shows that source and detector can be adequately protected. (*H* is elevation above floor of source and detector; γ is azimuth angle between source and detector azimuth angles)

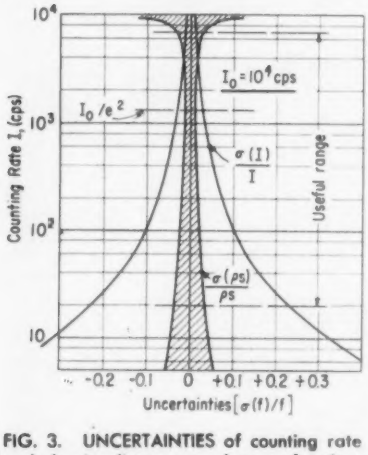

FIG. 3. UNCERTAINTIES of counting rate and density-distance product as functions of counting rate *I*. Values are computed for situation in which $I_0 = 10^4$ cps

Gas density has rarely been measured accurately, mainly because of lack of convenient instrumentation. But recent studies with charged particles have shown us how to record gas densities continuously under nearly all circumstances. Moreover the methods can be extended to record local variations of not only density but also flow rates, gas composition and temperature.

The most useful means for these purposes are properly adapted beta-ray gages. In some situations, however, electron beams from cathode-ray tubes are better; in others, alpha particles. Applications include 15-ft-diameter furnace flames, supersonic gas jets in a rarefied atmosphere and high-vacuum measurements at pressures below 10^{-6} torr (1 torr = 1 mm Hg).

For these purposes one can use any of several processes that occur when particles pass through a gas: scattering, energy loss, ionization, fluorescence. Using scattering and energy loss, one can build attenuation-type gages. Range-type gages can use energy loss of alpha particles. Based on large-angle single scattering of alpha and beta particles, new high-vacuum gages appear to be feasible. With intense electron beams, fluorescence probes have been devised for local gas densities; in some situations these probes can measure local temperatures, compositions and flow rates.

Electron Attenuation

For gas-density measurements in the range of atmospheric density, the most appropriate method is attenuation of beta rays or accelerated electrons. The first investigators used 100-kev electrons from a cathode-ray tube (*1, 2*). We realized that attenuation works even in rarefied gases, for which optical interferometers fail (*3*). In my own work I have shown how electron shadowgraphs of inhomogeneous gas regions can be obtained (*4*) and investigated conditions under which beta sources made of various nuclides can be used to measure gas density with beam attenuation (*5*).

Gages with an arrangement like that of Fig. 1 rely on the fact that under suitable conditions there is an exponential reduction in counting rate or electron-beam current: $I = I_0 e^{-\alpha\rho s}$ (I = counting rate per unit area or current density in amp/cm²; α = attenuation coefficient; ρ = gas density; s = distance between source and detector).* Fortunately α can be chosen over a wide range by selecting electron energy, and with the exception of hydrogen it is independent of atomic number. The irregular path of the individual electrons indicated in Fig. 1 is well known from cloud chamber pictures (*5a*).

Accuracy. A typical set of calibration curves for Sr^{90} (Fig. 2) shows that source and detector can be protected by rather thick metal foils without significant change in the value of α. This type of gage has operated satisfactorily for the past three years on the stack of a Linzer-Duesen steel furnace (*6*).

With increase of gas density or distance, counting rate decreases, and statistical fluctuations increase. At first it appears that these fluctuations are a great handicap, but when counting rate is converted to density, it becomes clear that a density change by a factor of ten can be covered accurately without changing the setup of the gage. Figure 3 shows both $\sigma(I)/I$ and $\sigma(\rho s)/\rho s$ as functions of I when I_0 is assumed to be 10^4 cps (σ is standard deviation). Superposition of the two functions shows the relation of one to the other. The second of these two functions has a minimum for $I = I_0/e^2$. (For a detailed discussion see ref. *5*.)

In Fig. 4 are shown the results when one uses a linear counting-rate meter and a logarithmic density scale. Here

* The exponential law usually does not hold when ionization is measured.

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the solid line shows ρs as a function of I, for $\alpha = 10$ cm²/gm and $I_0 = 10^4$ cps. On the plotted curve are superimposed values of $\sigma(I)$ for six selected values of I. When $\sigma(I)$ is projected horizontally onto the curve and this projection in turn is projected on the horizontal axis one gets an indication of the uncertainty in the density-distance product.

By plotting particle flux as a function of the density-distance product for electron beams of different energies and beta spectra from different nuclides, one can find the ranges over which electrons are suitable as gas-density probes. Radioactive sources are available for maximum density-distance products from 6×10^{-4} to 1 gm/cm². For small values of the density-distance product electron beams are more convenient than beta rays because they offer greater intensities. The lower limit for attenuation gages appears to be $\sim 10^{-6}$ gm/cm². Interesting applications of the attenuation method are to transient phenomena in shock waves and supersonic low-density gas flow (*7*, *8*).

An essential difference between the two types of sources is the behavior of the attenuation curve near the end of the range. For a monoenergetic source of 150 kev, the I/I_0 value at the end of the range is $\frac{1}{30}$. For C^{14} beta rays (150 kev max. energy), we find that I/I_0 is $\frac{1}{2000}$ (*5*). One consequence appears to be that when soft or hard

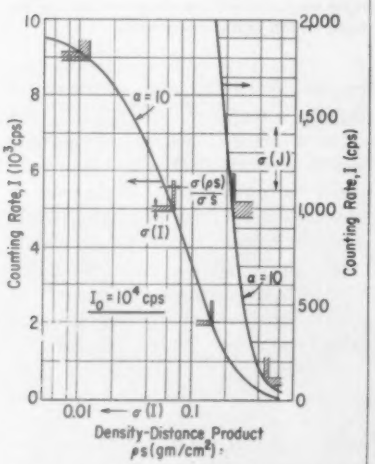

FIG. 4. DENSITY-DISTANCE PRODUCT as function of counting rate when meter is linear and density scale is logarithmic. Superimposed are uncertainties in both functions ($I_0 = 10^4$ cps)

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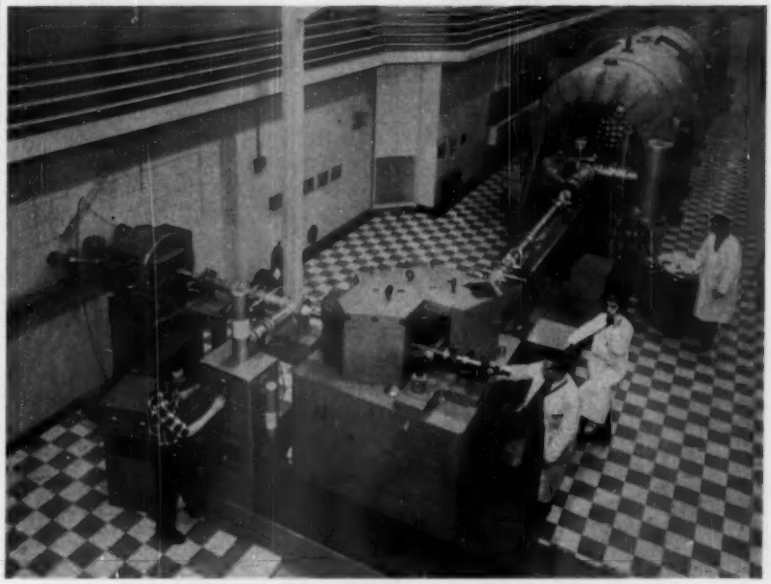

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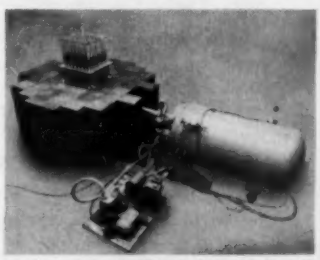

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beta rays are magnetically selected from any single nuclide, very little is gained for gaging purposes.

In the scattering field of an attenuation gage one can obtain shadowgraphs in a very simple way (*4, 9, 10*). The procedure is similar to that of taking X-ray pictures except that the attenuation coefficient of, say, 6 kev electrons is many times higher than that of X-rays. Thus even a gas jet at 2 torr can be shown as a shadow. In that range of density the most sensitive optical interferometers would fail. As in X-ray radiography, the limitations of the shadowgraph method are due to the mutually exclusive requirements for contrast and depth of field. Because of the low contrast we can not offer a good reproduction. After the limitations of the electron shadowgraphs were roughly explored (*4*), we looked for a still better method and devised the fluorescence probe.

Alpha-Range Gages

Since alpha particles are not appreciably scattered, their energy loss must be measured if they are to be used in a gas-density gage. The simplest way to do so is to measure their residual ionization, which is the method used by Schopper and Knapp (*3*) in a thermometer based on this effect. The essentials of this gage are shown in Fig. 5. At atmospheric density it detects relative changes of 1.5×10^{-3} ($\pm 0.5°$ C) with a time constant of 10^{-2} sec.

Because energy measurements are more complicated than straight particle counting, I have suggested several versions of an alpha-particle gage requiring only counters (*11*). In one example (as yet unbuilt), shown in Fig. 6, smaller gas density will make the energy of the alpha particles greater when they approach a wedge in front of a G-M counter. Thus more particles will penetrate this wedge as gas density is reduced. One can get the same effect from a thick alpha source from which particles are emitted with a spectrum of energies (*11a*).

The alpha-particle method has already been used for measurements on a flame (*12*) and in a set of experiments that compared stopping power in gases with stopping power in solids and liquids of the same composition (*13*).

Fluorescence Probes

Whereas beam attenuation can only provide us with average values of gas density integrated over a path, one often wants local values. Some time ago we confirmed that a fluorescence probe—a confined beam of electrons or ions causing fluorescence in gas through which it passes—can give us not only local gas densities but also local flow speeds, compositions and temperatures (*14*). Beams from radionuclides are usually too weak for this purpose, but an electron beam from a gun that has a dynamic pressure stage as an exit is readily applied (*9, 14a*).

In cooperation with the Institute of Aerophysics, University of Toronto, we used an arrangement of this kind in a low-density wind tunnel (Fig. 7) (*15*). Our purpose was to study feasibility of local-density determinations in super-

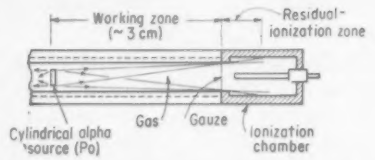


FIG. 5. THERMOMETER using gas attenuation is sensitive to 0.5° C and has time constant of 0.01 sec

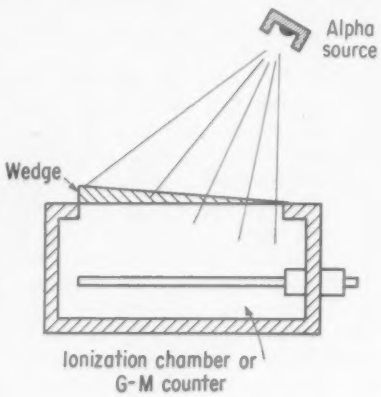


FIG. 6. ALPHA-RANGE GAGE uses wedge to make counting rate sensitive to gas-density changes around it

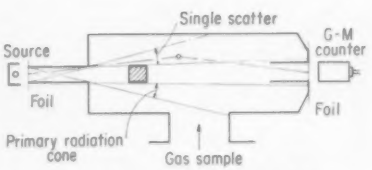
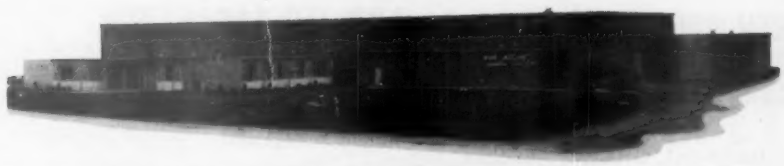


FIG. 7. FLUORESCENCE GAGE in wind tunnel observes glow from gas excited by a confined electron beam electrons. At right angles to electron beam is window for observation and photography



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1958: AMF Atomics Canada entered contractual agreement with Eldorado Mining & Refining, Ltd., to supervise processing, inspection, and health physics programs, plus assumption of accountability for CASTING and ROLLING of metal.

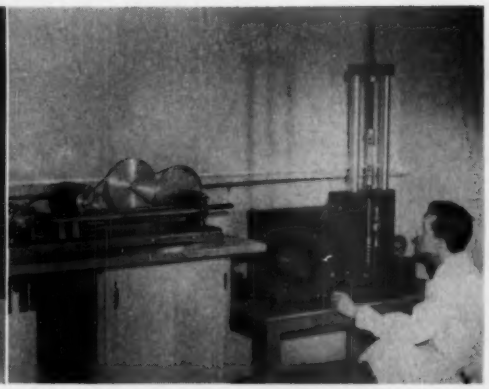
1958: AMF entered long-term contract with A.E.C.L. to develop designs of UO_2 Zircaloy-clad power reactor fuel elements and manufacturing techniques. Equipment for full-scale production was subsequently installed. AMF can now supply the entire Canadian power program, as well as needs elsewhere in the world.

1959: AMF fabricated core loading for ZEEP low power reactor at Chalk River, using ceramic UO_2 pellets.

1959-60: AMF became associated with the CANDU program, the first commercially-sized Canadian power reactor (200,000 KW electrical). AMF produced prototype elements under long-term contract to A.E.C.L.

AMF awarded first commercial contract for fabrication of fuel for JRR-3 reactor by Japan Atomic Energy Research Institute.

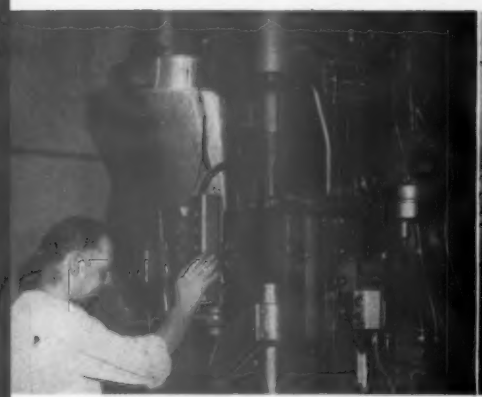
2. Inspection of extrusion-clad natural uranium flat plates for NRU reactor at Chalk River.



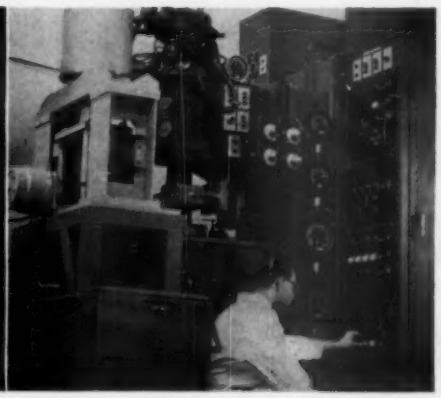
3. A materials testing laboratory aids in the development of power reactor elements.

4. Fuel elements produced by AMF: (1) Sectioned NRU element; (2) Sectioned NRX element; (3) Power reactor element consisting of UO_2 pellet-filled Zircaloy tubes; (4) Single Zircaloy tube; (5) UO_2-filled, aluminum-clad element; (6) CANDU fuel bundle; (7) UO_2 pellets in stages of production.

5. Cladding NRU flat plate cores with aluminum by direct extrusion process.



6. This machine automatically forms precision ceramic UO_2 fuel pellets.



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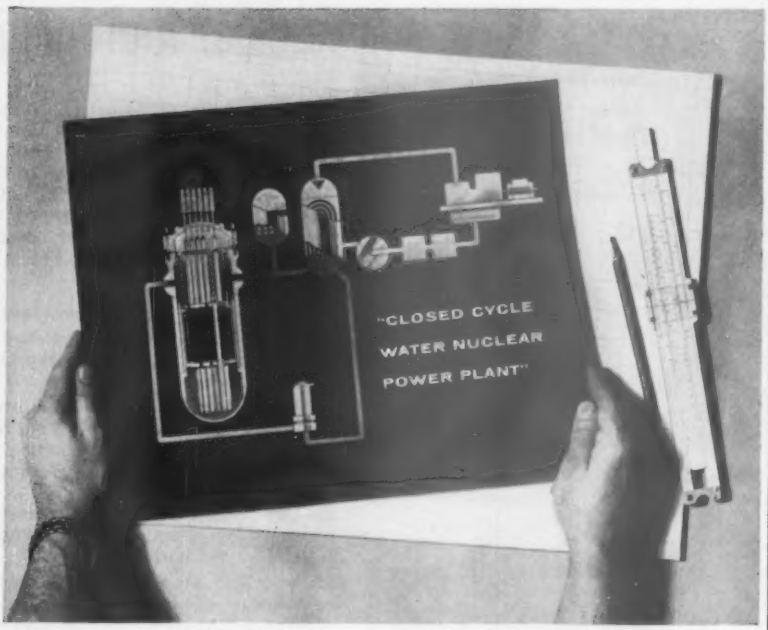

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This article starts on page 106

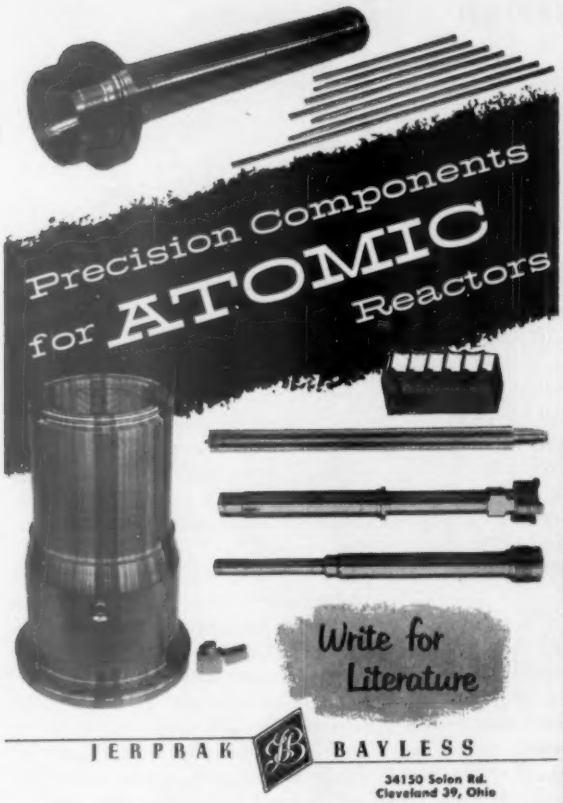
sonic flow using a confined electron beam of approximately 60 kev and 200 μ amp. If spectral lines that have no afterglow are selected, light output along the beam is proportional to gas density. Light output is not affected by flow, and calibration is linear at pressures smaller than ~1 torr. Calibration for higher pressures is possible. Gruen has made studies of absolute fluorescence yield (*16*).

The practical low-pressure limit for fluorescence probes in air is $\sim 10^{-5}$ torr. These probes can be used (at night) to measure air-density profiles around a high-flying aircraft in free flight.

One can also make use of the afterglow, which is particularly prominent in some gases excited by a discharge (nitrogen is an example). Afterglow is carried away by fast flow, and since excitation by our confined beam is restricted to a narrow region (diameter ~0.5 mm), length of the afterglow vane is a measure of flow speed (see Fig. 8). We can probably increase the accuracy of these flow measurements if we pulse the exciting beam and use stroboscopic observation (*14*). This eliminates the need of knowing the decay constant and other parameters of afterglow.

Gas composition is revealed by spectrographic analysis of luminescence. In contrast to an electric spark, an electron beam of, say, 20 kev excites all gas components. Gruen has demonstrated the method qualitatively (*17*). If the trace of an electron beam like that of Fig. 8 is imaged on the slit of a spectrograph parallel to the beam, each spectral line is a picture of the trace. Gas composition in or near a gas jet (including products formed in the electron beam itself) may be different from that in stagnant gas. This is apparent in the resulting spectrograms.

One can also deduce local gas temperature from the band structure in the usual way. In the spectrogram temperature differences between gas in the jet and that of surroundings are clearly indicated; jet gases are colder than those around them because of their expansion as they enter the chamber; hence the higher energy levels of the band are not excited and do not show. Since both jet gases and surrounding ones are under the same pressure, the lower temperature in the jet produces increased gas density. This increased density is revealed by greater luminous intensity of those spectral lines not



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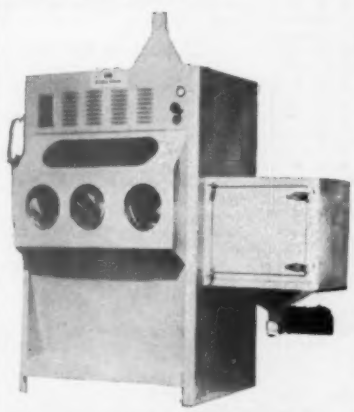

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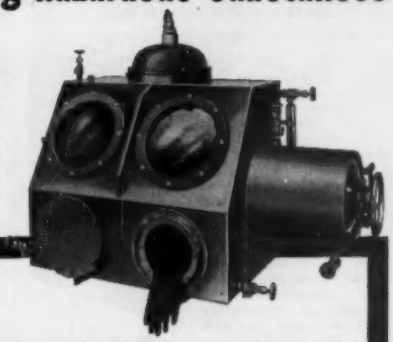

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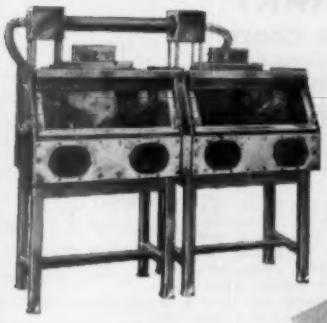

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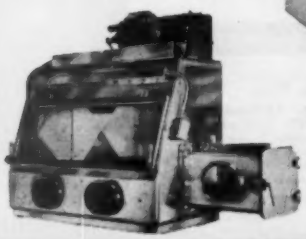

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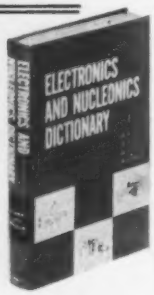

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affected by temperature. Only these lines can be used for density probes.

Back-Scatter Gages

One company is designing high altitude altimeters using the back-scattering of beta rays by gas (*21*). The main advantage is the neat geometric arrangement of source and detector possible with this system. The low-density limit is determined by the noise of the detector. This is the principle weakness of any back-scatter gage. The particles when scattered backwards by multiple collisions loose most of their initial energy which, to achieve high sensitivity, is kept low. A gage using a source of 4 mc Pr-147 and a scintillation detector has worked well at a pressure of 25 torr (~66,000 ft altitude).

Single-Scatter Gages

For densities smaller than the low-density limits of back-scatter gages and fluorescence probes one can use single-scatter gages in which one counts particles scattered by a small angle only once. I have suggested a system that could probably measure densities at pressures as small as 10^{-8} torr corresponding to an altitude of 200 miles (*18*). One could probably use convenient radioactive sources and eliminate the need for electron guns.

One of the arrangements I have proposed consists of an alpha- or beta-ray source, limiting apertures for the beam, and a detector so arranged that in a perfect vacuum none of the beam particles can reach the detector; counting rate would be zero. When gas molecules are present, some particles would be scattered into the detector; counting rate would increase with density. The particle energy is close

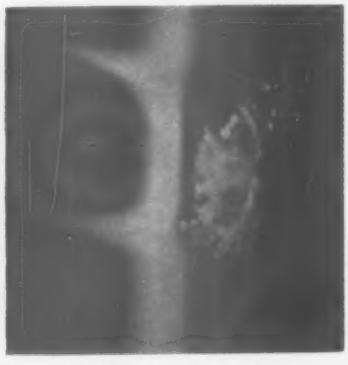

FIG. 8. AFTERGLOW reveals flow speeds in wind-tunnel jet. Spectroscopy permits one to see it or ignore it

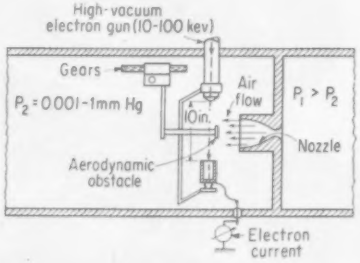

FIG. 9. HIGH-VACUUM GAGE would be rugged and independent of gas flow

to the one at the source, and detection with discrimination against background is easy. Some single-scatter systems have already been built with electron-optical systems under dark-field conditions (*19, 20*).

I have also suggested using the single-scatter principle in a high-vacuum gage (*18*). Such a system would be the first alternative to the ionization gage, notoriously unreliable, or the Knudsen gage, a very delicate instrument. The gage consisting of just a radionuclide source and an alpha- or beta-particle detector will be very rugged and independent of gas flow and temperature. Only by experiment can this be demonstrated and a practical working gage developed.

BIBLIOGRAPHY

1. C. Ramsauer, *Elektrotech. u. Maschinenbau* **51**, 189 (1933)
2. A. von Engel, M. Steenbeck, *Wiss. Veroeffentl. Siemens-Konzern* **12**, 74 (1933)
3. E. Schopper et al., *Physik Verhandl.* **6**, 73 (1950), *Z. Naturforsch.* **6a**, 700 (1951), *Z. angew. Phys.* **6**, 198 (1954)
4. B. W. Schumacher, *Ann. Phys.* (6) **13**, 404 (1953)
5. B. W. Schumacher, Ontario Research Foundation Physics Research Report 6001 (January 18, 1960)
5a. H. Raether, *Ergeb. exakt. Naturw.* **22**, 73 (1949)
6. B. W. Schumacher, W. Wojcik, R. C. Zavitz, to be published
7. D. Venable, D. E. Kaplan, *J. Appl. Phys.* **26**, 539 (1955)
8. F. C. Hurlbut, *J. Appl. Phys.* **30**, 273 (1959)
9. B. W. Schumacher, *Optik* **10**, 116 (1953)
10. A. E. Gruen, E. Schopper, B. W. Schumacher, *J. Appl. Phys.* **26**, 1527 (1953)
11. B. W. Schumacher, Ontario Research Foundation Record, No. 11 (September 25, 1959)
11a. R. H. Ellis, private communication
12. A. Shirodkar, *Phil. Mag.* (7) **15**, 426 (1933)
13. R. H. Ellis, Jr., *Rev. Sci. Instr.* **25**, 336 (1954); R. H. Ellis, Jr., H. H. Rossi, G. Failla, *Phys. Rev.* **97**, 1043 (1955)
14. B. W. Schumacher, A. E. Gruen, German Patent Application Sch 18144IXb/42L (June, 1955); U. S. Patent Application No. 759,239 (September, 1958)
14a. Ontario Research Foundation Physics Research Report 5806 (December, 1958)
15. B. W. Schumacher, E. O. Gadamer, *Can. J. Phys.* **36**, 659 (1958)
16. A. E. Gruen, *Can. J. Phys.* **36**, 858 (1958)
17. A. E. Gruen, *Z. Naturforsch.* **9a**, 833 (1954)
18. B. W. Schumacher, Ontario Research Foundation Record No. 13 (October 5, 1959), No. 27 (March 16, 1960)
19. H. Boersch, *Z. Physik* **107**, 493 (1937)
20. L. Marton, D. C. Schubert S. R. Mielczarek, *J. Appl. Phys.* **27**, 419 (1956)
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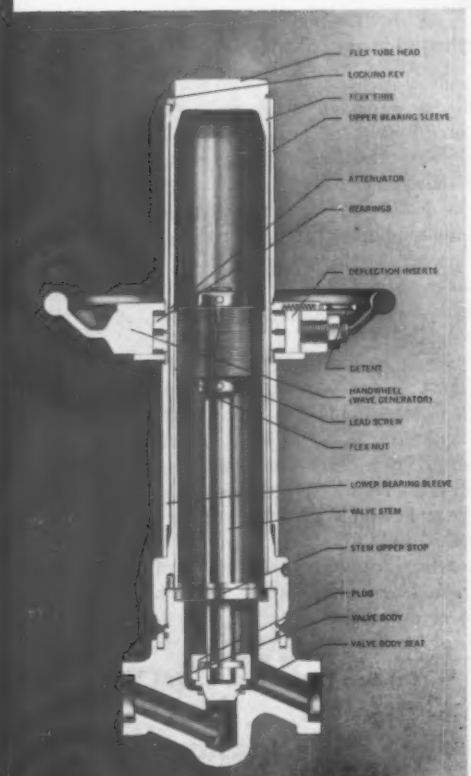

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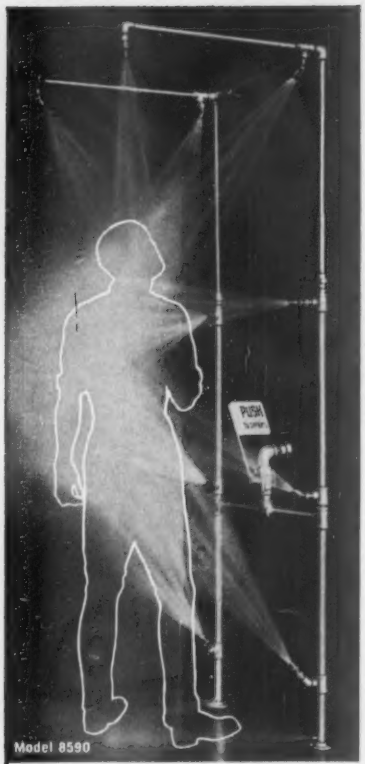

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Industrial Tracer Applications in Canada

By GEOFFREY G. EICHHOLZ
Department of Mines and Technical Surveys, Ottawa, Ontario

Radionuclide-tracer uses have not grown as rapidly throughout the world as the more sanguine predictions of the early postwar years suggested. Reasons for this are apparent from Canadian industrial experience, too. Moreover, certain special problems have arisen in connection with Canada's emergence in the past two decades from the status of a raw-materials producer to the position of a significant industrial power. One such problem is the tendency for much of the research and development work to be done by "parent companies" in the United States, Great Britain, and elsewhere. Ample opportunities, however, still exist in our industries for applying and extending the use of tracers.

In contrast to the reluctance of industries to accept tracer techniques, the medical and biological professions in Canada make widespread use of radionuclides. Medical science is vitally dependent on the use of the most modern techniques in its search for new tools to combat disease. Thus, it enlists radionuclides for diagnosis and treatment.

Why Slow Development?

Large capital investment in plant facilities coupled with an inherent sense of conservatism frequently discourages attempts to change existing processes in Canadian industry. Widespread use of radioactive materials for test purposes in metallurgical plants has also encountered obstacles from an overly cautious interpretation of food and drug laws. A further deterrent has been the unreasonable emphasis given in many publications to problems surrounding safe handling of radionuclides. By implying that heavy capital expenditures are necessary before radioactive tracers can be used, such articles have scared many industrial managers away.

In view of these deterrents, few private companies in Canada have engaged in industrial tracer activities. Most of the work in the field is carried out with the assistance of two Canadian Government agencies, the Commercial Products Division of Atomic Energy of Canada Ltd. and the Mines Branch of the Department of Mines and Technical Surveys. The bulk of such tracer work is handled by the Mines Branch, which, not being a commercial organization, is able to assist industry in the tracer field at nominal cost. Private firms that have entered the industrial radiation field have usually confined themselves to instrumentation development (particularly radioactivity density and thickness gauges) and to industrial radiography with portable radioactive sources. The full potential of tracer techniques in Canada, as elsewhere, will not be realized until there is a more realistic approach to the employment of radioactive materials in industry. This requires a nonsensational explanation of the commercial benefits and the type of tests feasible under nonlaboratory plant conditions.

Industrial Tracer Work

A general survey of Canadian applications of radioactive materials was presented by Spinks (*1*) in 1958.

Since considerations of public safety make routine use of radioactive materials in unsealed form undesirable for continuous manufacturing operations, most tracer applications in Canada have been batch tests done only during special investigations of operating conditions. An exception is the labeling of copper balls with Ag^{110} to facilitate inspection for their inclusion as gas checks in the assembly of ammunition shell primers (*2*). The method was employed after separate tests had established that with special handling, storage and disposal of shells, no health hazard existed.

Analytical chemistry is a field of considerable industrial interest in which radioactive tracers are widely used. Jarvis of Chalk River and the Univer-

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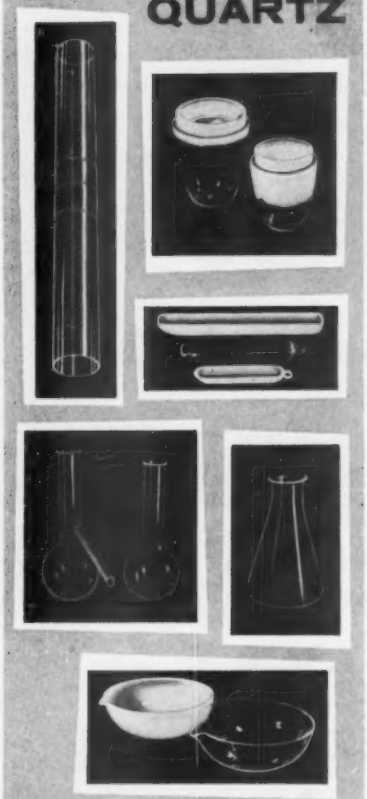

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sity of Toronto has worked on activation analysis of zirconium alloys and other metals (*3*), and Faye and Inman at the Mines Branch are developing analytical procedures for niobium and tantalum (*4*) and assay procedures for silver, iridium and other precious metals (*5, 6*). The extraction of thorium and rare earths from uranium ores using ion-exchange columns has been studied by Lewis and Ingles (*6a*), who employed Eu^{152} and La^{148} as tracer nuclides.

Metallurgy. Radioactive tracers have been used in a variety of Laboratory studies of interest to the metallurgical industries. Notable are the experiments on grain-boundary segregation of trace impurities in pure zinc and aluminum samples by Weinberg at the Mines Branch (*7*) and Chalmers and Winegard at the University of Toronto (*8*). Investigations on exchange processes between pure metals (particularly zinc and silver) and their ions in aqueous solutions, important in corrosion studies, have been conducted at the Mines Branch by Sandor (*9, 10*). Eichholz and Roberts have studied other surface reactions, with emphasis on those of interest in flotation processes (*10a*). These reactions are currently being investigated further at the Mines Branch.

The Branch has recently developed various radioactive-tracer methods to determine the precise surface areas of coarse metal powders employed in the bomb-reduction production of special metals like uranium and zirconium. These methods include measurements of surface areas of coarse magnesium and uranium-oxide powders. In the former, the absorption of Cr^{51} (*11*) and C^{14}-labeled oleic acid (*12*) is determined, and in the latter, P^{32} (*13*) is used.

Flow Rates and Contact Times

Two tracer-application fields of particular interest in Canada are measurement of flow rates and contact times and measurement of wear and grinding rates.

Radionuclides are well adapted to tracing flows of coarse and fine particles through complex industrial installations (*14*). They are widely employed for checking flow conditions in pipelines and water streams. Less known is their use in detailed investigations of flow conditions and intricate particle motion.

The following are some of the Canadian investigations carried out in this field: Mason *et al.* at the Pulp and Paper Research Institute conducted flow tests on Fourdrinier paper machines using I^{131} as the tracer (*15*). They also studied the removal of lignin from wood in commercial sulfite-cooking procedures. In another experiment, using

Nontracer Radiation Applications in Canada

In addition to the radiotracer applications discussed in the accompanying article, Canadians have made substantial contributions to the field of radiation applications. In the medical field not only is the Commercial Products Division of Atomic Energy of Canada Ltd. the world's leading supplier of cobalt-60 beam-therapy units but such Canadian institutions as the Ontario Cancer Institute (and the associated Princess Margaret Hospital, devoted entirely to radiation therapy) have evolved techniques for their use. The Institute's Physics Division, led by H. E. Johns, has been active in all phases of radiation physics including such new areas as the detection of free radicals in biological materials using electron-spin resonances.

At the Defense Research Chemical Laboratories in Ottawa, research includes the electrochemical effects of ionizing radiation and the prospects for using these effects to build (a) an electrochemical radiation dosimeter and (b) an electrochemical converter of radiation energy into electrical energy.

Radiation chemistry is represented by the fundamental studies of P. J. Dyne and collaborators at Chalk River on the radiation chemistry of water and such workers as A. Back at McGill on the radiation chemistry of radiocarbon gases.

Radiation-improved products are represented by the work that AECL-CPD has done in collaboration with various of its customers. In particular, R. J. Richardson has improved the water-resistance of nylon tenting fabrics by means of radiation-grafting. Some of this work will be reflected in articles in forthcoming issues of NUCLEONICS.

simulated wood chips containing radioactive lanthanum and following their path through the machines with arrays of G-M counters, Tolmie and Churchill investigated the movement of wood chips through large digesters (*16*). Flow of ore particles and specific reagents in leaching-circuits had been followed through linear series of leach tanks (*17*), closed circuits (*18*) and flotation circuits (*19*). This work has indicated how short-circuiting and excessive recycling can be avoided in the design of such tanks and cells. Similarly, a number of tracer tests have been done to determine the residence times of charges in furnaces and kilns used in metallurgical processes. Tests yielding valuable information on furnace operations range from iron-ore arc smelting (*20*) and copper smelting to the kiln roasting of titanium ore (*21*).

Such tests brought out the confusion that surrounds the interpretation of the term "contact time" (or "residence time" as it is sometimes called*). Conventional engineering practice defines residence time simply as the ratio of the volume of the system to the flow rate. This definition applies properly only to perfect streamline flow and does not take into account any mixing or recirculation. This discrepancy can be seen by comparing Fig. 1, obtained in a rotary-kiln test (*21*), with no tracer dispersion, and Fig. 2, which shows the experimental results obtained in a tracer test on a smelter with complete and rapid dispersion of the tracer (*19*). Clearly the term "residence" time cannot mean the same in both situations. In the first, the time elapsed between the insertion of the tracer material into the kiln and its ejection at the discharge can be described as its residence time even though its metallurgical effectiveness might have been increased by greater dispersion. In the second case, the discharge of active material follows a logarithmic law. The time interval between insertion of the tracer and the moment of maximum rate of discharge is not the same as the average time that a portion of the tracer spends in the vessel. In this case, the mean residence time is derived from the slope of the logarithmic time plot.

Between these extremes there can be limited dispersion of material flowing through the system, and the residence time can be derived by a comparison

How Dispersion Affects Tracer Flow, Residence Time

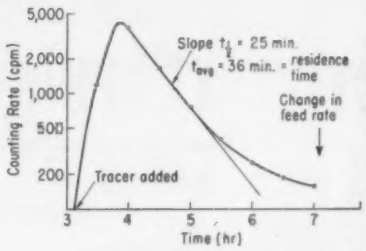

FIG. 1. COMPLETE DISPERSION of tracer results in exponential decay of counting rate with time as tracer is eliminated from system. Here mean residence time is best derived from slope of exponential decay. Ag^{110} tracer measured at outflow in test of kiln production of Al_2O_3

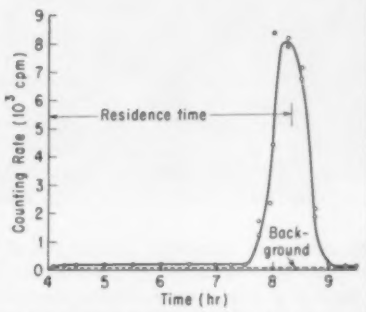

FIG. 2. NO DISPERSION results in tracer being eliminated in one slug. Here residence time is best defined as time from injection of tracer (4 P.M.) to its ejection at the discharge (8:20 P.M.). Ag^{110} used as tracer with coarse samples in smelter test

of linear and logarithmic plots of discharge activity. Such a residence-time determination provides information on mixing and dispersion conditions as well as bulk movement of material.

Wear and Grinding Rates

Tracer techniques are applied to the study of tool wear and operating wear of bearings. These tests have usually involved the irradiation of a single important part, such as a piston ring, and a determination of its gradual loss of activity or the appearance of active material in the lubricant.

Tracers have also been used to determine the wear rate of grinding balls of different compositions under operating conditions in a large ball mill (*22*)

Conclusions

This review has been necessarily somewhat cursory, but it has aimed at demonstrating how valuable industrial information can be obtained by rela-

* In this discussion, the terms residence time and contact time are used interchangeably; the appropriate term for a given system is usually self-evident.

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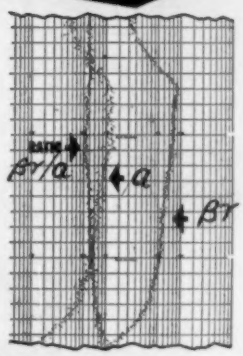

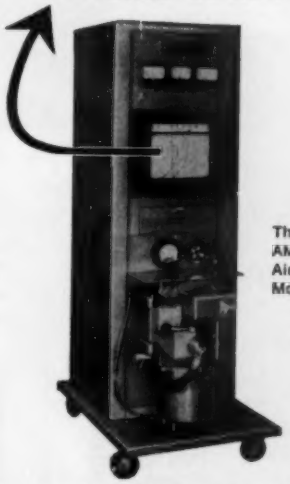

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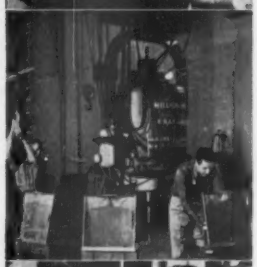

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tively simple and inexpensive tests with radioactive tracers. While there have been gains, the full potential of the radioactive tracer method will not be realized until there is a more realistic approach to the employment of radioactive materials in industry. This requires further, nonsensational explanations of commercial benefits and tests feasible under plant conditions.

BIBLIOGRAPHY

1. J. W. T. Spinks in "International Conference on the Peaceful Uses of Atomic Energy," vol. 19, p. 13 (United Nations, Geneva 1958)
2. G. G. Eichholz, C. M. Lapointe, G. E. Alexander, *Int'l. J. Appl. Radiation and Isotopes*, **5**, 51 (1959)
3. R. E. Jarvis, W. D. Mackintosh, in "Int'l. Conf. on Peaceful Uses of Atomic Energy," vol. 28, p. 470 (United Nations, Geneva 1958)
4. G. H. Faye, W. R. Inman, *Trans. Can. Inst. Mining Met.* **60**, 343 (1957)
5. G. H. Faye, W. R. Inman, *Anal. Chem.* **31**, 1072 (1959)
6. G. H. Faye, W. R. Inman, *Talanta* **3**, 277 (1959)

6a. D. C. Lewis, J. C. Ingles. Studies on the separation of the rare earths from thorium in sulphate solutions, using cation exchange resins, Mines Branch Research Report R 31 (Dept. of Mines and Technical Surveys, 1958)

7. F. Weinberg. Grain boundaries in metals, Mines Branch Research Report R 44 (Dept. of Mines and Technical Surveys, 1958)
8. W. R. Thomas, B. Chalmers, *Acta. Met.* **5**, 118 (1957)
   W. C. Winegard, *Am. Foundryman* **23**, No. 4, 140 (1953)
9. J. E. Sandor. Exchange reactions between zinc and its ions, Mines Branch Research Report R 58 (Dept. of Mines and Technical Surveys, 1959)
10. J. E. Sandor. Surface exchange reactions of silver and its ions, Mines Branch Research Report R 62 (Dept. of Mines and Technical Surveys, 1960)

10a. G. G. Eichholz, W. N. Roberts in "International Conference on the Peaceful Uses of Atomic Energy," vol. 19, p. 240 (United Nations, Geneva 1958)

11. H. P. Dibbs. Surface area determination of magnesium powder with Cr-51 tracer solutions, Mines Branch Research Report R 53 (Dept. of Mines and Technical Surveys, 1959)
12. C. M. Lapointe. Surface area determination of magnesium powders by sorption of C^{14}-labeled oleic acid, Mines Branch Research Report R 60 (Dept. of Mines and Technical Surveys, 1960)
13. P. R. Gorla (in press)
14. C. G. Clayton, NUCLEONICS **18**, No. 7, 96 (1960)
15. S. G. Mason, W. Rabinovitch, *Proc. Roy. Soc.* (London) **A 249**, 90 (1959)
16. R. W. Tolmie, T. R. Churchill. Tracing of tagged chips through two Kamyr continuous digesters, AECL 60-4-RD-12 (1960) (unpublished)
17. J. C. Turgeon, *Trans Can. Inst. Mining Met.* **59**, 14 (1956)
18. G. G. Eichholz. The use of radioactive tracers in ore treatment problems, Mines Branch Report TR-149/57 (Dept. of Mines and Technical Surveys, 1957)
19. G. G. Eichholz, et al. *Trans. Can. Inst. Mining Met.* **60**, 63 (1957)
20. G. G. Eichholz. Radioactive tracer tests during an arc-furnace pilot run, Mines Branch Investigation Report IR 58-127 (Dept. of Mines and Technical Surveys) (unpublished)
21. G. G. Eichholz. Measurements of kiln contact time at Freeman Corp. Trois Rivieres, P. Q. Mines Branch Investigation Report IR 60-12 (Dept. of Mines and Technical Surveys, 1960) (unpublished)
22. J. D. Keys, G. G. Eichholz. Measurement of wear rate of cast grinding balls using radioactive tracers, Mines Branch Technical Bulletin TB 18 (Dept. of Mines and Technical Surveys, 1960)

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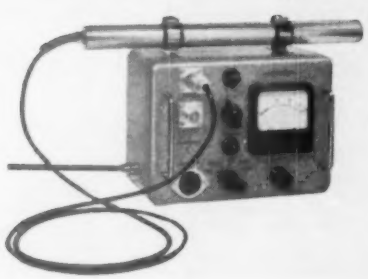

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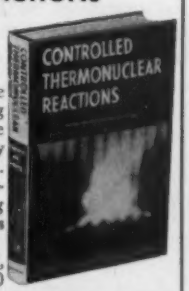

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fundamental physical processes involved. The aspects being studied are those associated with present or potential limitations on the fuel-element design in the belief that a better understanding will allow a more economical or more efficient design. A knowledge of the temperature distribution and the factors that affect it are basic requirements in any such investigation.

UO_2 thermal conductivity. Ross (*28*) has shown that the thermal conductivity of sintered UO_2 is not dependent on the porosity in the manner generally accepted (see Fig. 6) and has indicated that the shape of the pores is important. He has also shown (Fig. 6) how oxygen in excess of the stoichiometric composition decreases the conductivity at low temperatures, probably by the introduction of low-conductivity U_4O_9.

The effect of irradiation on the conductivity of UO_2 has been studied by several methods: using thermocouples during irradiation, observing structural changes due to irradiation, and conventional determinations on irradiated pellets, with and without subsequent annealing. The results are summarized in Fig. 6. The "hydraulic rabbit" in NRX (*11, 14, 33*) provides a technique for measuring the effect of additives on UO_2 thermal conductivity under irradiation. For example, 4 mol% Y_2O_3 provides no benefit (*34*) despite earlier hopes (*35*).*

Fuel-sheath interface. The greatest uncertainty now lies in the fuel-to-sheath temperature drop. In most practical fuel-element applications, there is an interfacial pressure of about 100 atmospheres between the two. Until recently, however, there has been no experimental determination of heat-transfer coefficients between metals and ceramics for this order of pressure.

Early results by Ross (*36*) have shown that the advantage gained by substituting helium for argon is small, presumably because of the smaller accommodation coefficient of the former (*37*). The same conclusion had been drawn (*14*) from a comparison of helium- and argon-filled irradiation specimens.

Mechanical properties. Since an operating fuel element represents an equilibrium condition between the thermal expansion of the fuel and the restraint imposed by the sheath and coolant, any stress analysis requires knowledge of the mechanical properties of both fuel and sheath.

Tensile tests (*38*) have shown how the strength of Zircaloy-2 is increased by neutron irradiation. Hydrogen, when precipitated as hydride, embrittles Zircaloy but has very little effect on the tensile strength. Little is known of the relevant properties of UO_2, beyond that it is appreciably plastic at 2,000° C as shown by its movement into the end-face dishing of pellets (*4*); the University of British Columbia is investigating the deformation behavior of UO_2 at high temperatures.

Fission gases. The pressure exerted on the sheath by the fission gases is a complicated function of many variables. Although much has been learned (*13*) concerning how the O:U ratio of the uranium oxide and the microscopic structure of the sinter affect diffusional release, the roles played by grain boundaries and free surfaces are not established. That rare gases are driven into UO_2 during irradiation has been proved by the presence of natural isotopes of the gas in samples collected from dissolved fuel (*39*). However, a reliable estimate of the magnitude of this effect in practical fuel elements requires further experiments.

It is hoped that the continuation for a few more years of an experimental program of this nature will permit designing a UO_2-bearing fuel element for any application with a minimum of empirical testing.

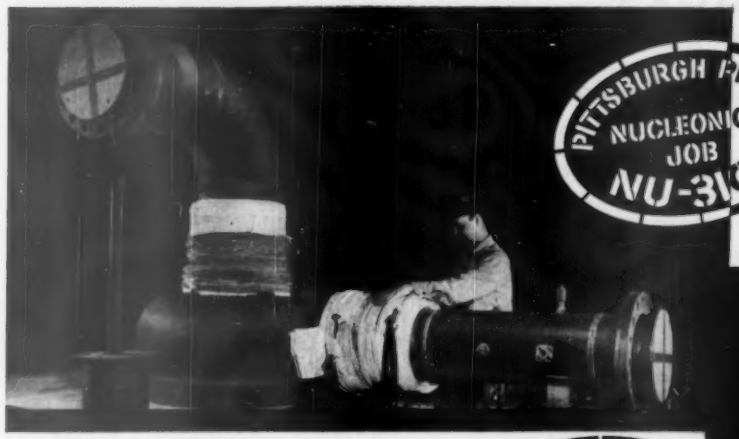
* * *

Many of those in AECL and other Canadian organizations mentioned have contributed directly or indirectly to the fuel-development program. Further, the authors wish to acknowledge the benefit received from cooperation with other laboratories, especially Bettis, Hanford and Harwell.

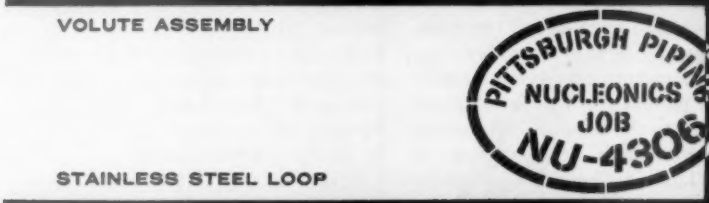
BIBLIOGRAPHY

1. J. D. Eichenberg, *et al.* Effects of irradiation on bulk UO_2, WAPD-183 (1957)
2. J. A. L. Robertson, *et al.* Behaviour of uranium dioxide as a reactor fuel, in Proceedings of Second International Conference on the Peaceful Uses of Atomic Energy, vol. 6, p. 655 (United Nations, Geneva, 1958)
3. O. J. C. Runnalls. UO_2-fabrication and properties, NUCLEONICS **17**, No. 5, 104 (1959)
4. J. A. L. Robertson, *et al.* Irradiation behaviour of UO_2 fuel elements, "Nuclear Metallurgy," Vol. 6 (1959)
5. A. S. Bain, J. A. L. Robertson. Effects of O:U ratio on the irradiation behaviour of uranium oxide, *J. Nucl. Materials* **1**, 109 (1959)
6. F. H. Krenz, *et al.* Chalk River experience with Zircaloy-2 and aluminum-nickel-iron alloys in high temperature water, in Geneva proceedings, vol. 5, p. 241 (1958)
7. A. J. Mooradian, *et al.* Chalk River experience with fuel waterlogging, NUCLEONICS **18**, No. 1, 81 (1960)
8. W. B. Lewis. Canada's steps towards nuclear power, in Geneva proceedings, vol. 1, p. 53 (1958)
9. J. A. L. Robertson. $\int kd\theta$ in fuel irradiations, AECL Report CRFD-835 (1959)
10. M. L. Bleiberg, *et al.* Burn-up limitations of bulk UO_2 prototype fuel elements, WAPD-229, Bettis Technical Review BT-18 (1960)
11. A. S. Bain, J. A. L. Robertson. UO_2 irradiations of short duration, CRFD-825 (1959)
12. V. B. Lawson, J. R. MacEwan. Thermal simulation experiments with a UO_2 fuel rod assembly, CRFD-915 (1960)
13. W. H. Stevens, *et al.* The diffusion behaviour of fission xenon in uranium dioxide, presented at First Conf. on Chem. in Nucl. Reactor Technology, Gatlinburg, Tennessee (1960)
14. A. S. Bain, *et al.* UO_2 irradiations of short duration, part II, CRFD-955 (to be published)
15. J. D. Eichenberg, *et al.* Irradiation of UO_2 fuel rods—the X-1-l experiment, WAPD-208 (1960)
16. W. Evans, F. H. Krenz. The X-2-t test: examination of H pick-up in specimen LR, AECL-Exp-NRX-2904 (1960)
17. W. Evans, F. H. Krenz. CR-V-n NPD-2 trefoil irradiation: analysis of H pick-up in sheath of specimen K-2, AECL-Exp-NRX-3105 (1960)
18. G. J. Biefer, unpublished work at Chalk River, reported in ref. *16*
19. G. M. Allison, I. H. Crocker. Chemistry of defect test on highly-rated sintered UO_2 fuel test X-2-q, AECL-Exp-NRX-1806 (1959)
20. A. S. Bain, J. A. L. Robertson. Behaviour of highly-rated uranium oxide specimens irradiated with a defected sheath, test X-2-q, AECL-Exp-NRX-1807 (1960)
21. G. M. Allison, *et al.* Chemistry of the first UO_2 fuel failure in the X-2-s test, July 1959, AECL-1012
22. G. H. Chalder. Problems in the use of thin Zircaloy cladding for uranium dioxide fuel, Paper FE/19/1.3 of IAEA Symposium on Fuel Element Fabrication, Vienna (1960)
23. D. C. Martin, *et al.* Joining of zirconium, in "The Metallurgy of Zirconium," ch. 7, Lustman and Kerze, ed. (McGraw-Hill Book Co., New York, 1955)
24. C. A. Crawford. The fretting corrosion of Zircaloy-2: a preliminary study, AECL-CRMet-857 (1960)
25. W. W. Kirk. Ni-free Zircaloy-2 H pick-up program, WAPD-NCE-607 (1958)
26. E. C. W. Perryman. A review of Zircaloy-2 and Zircaloy-4 properties relating to the design stress of CANDU pressure tubes, AECL-CRMet-937 (1960)
27. H. Schwartzbart. "Brazing of Zircaloy," AIME Symposium on Reactive Metals (Interscience Publishing Co., New York, 1959)
28. A. M. Ross. The effect of density, microstructure, stoichiometry and thermal-neutron irradiation on the thermal conductivity of uranium dioxide, CRFD-817 (1960)
29. W. D. Kingery, *et al.* Thermal conductivity: X data for several pure oxide materials corrected to zero porosity, *J. Am. Cer. Soc.*, pt. 2, **37**, p. 107 (1954)
30. R. Scott. Thermal conductivity of UO_2, UKAEA Report AERE-M/R-2526 (1958)
31. C. F. Lucks, H. W. Deem. Thermal conductivity and electrical conductivity of UO_2, BMI-1448, Section J-1 (1960)
32. M. L. Bleiberg. Technical progress report, Pressurized Water Reactor (PWR) project, for the period June 24, 1959 to August 23, 1959, WAPD-MRP-81 (1959)
33. J. G. Melvin. NRX hydraulic rabbit facility, AECL-NEI-107 (1959)
34. J. A. L. Robertson, *et al.* The effect of 4 mol. % Y_2O_3 on the thermal conductivity of UO_2, CRFD-933 (1960)
35. H. Shapiro, R. M. Powers, SCNC-271 (1959); NUCLEONICS **17**, No. 11, 156 (1959)
36. A. M. Ross, unpublished work at Chalk River
37. J. K. Roberts. "Heat and Thermodynamics," 3rd ed. (Blackie, London, 1942)
38. L. M. Howe, W. R. Thomas. The effect of neutron irradiation on the tensile properties of Zircaloy-2, *J. Nucl. Materials*, **2**, 3 (1960)
39. W. B. Lewis. The return of escaped fission product gases to UO_2, AECL-DM-58 (1960)
40. W. B. Lewis. Competitive nuclear power for Canada, NUCLEONICS **18**, 10, 54 (1960)

* See, on p. 6, the communication from R. M. Powers for detailed comment on Y_2O_3 additive.



VOLUTE ASSEMBLY



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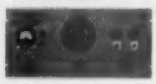

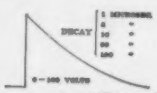

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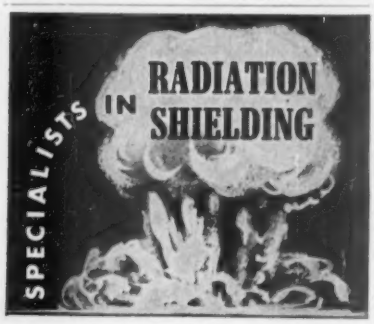

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Cumulative lists of these publications are issued every one or two years with supplements at intervals between. These lists and other information about AECL's publications can be obtained by writing to the Scientific Documents Distribution Office, Atomic Energy of Canada Limited, Chalk River, Ontario, Canada.

Copies of all Chalk River reports are sent to the 84 university and public libraries in the U. S. that have been designated as depositories by the USAEC. They are also sent regularly to libraries and other institutions in a total of 30 countries. They are reviewed promptly by Nuclear Science Abstracts.

Typical of the technical reports released this year are:

L. M. Howe. Irradiation behavior of enriched U_3Si elements sheathed in Zircaloy-2, AECL-984, 59 pp., $2.00. (*Swelling was negligible up to 600 Mwd/tonne, but amounted to 7% by 1,600 Mwd/tonne.*)

Proceedings of the Industrial Symposium, Chalk River, AECL-990, 196 pp., $2.50. (*Sixteen papers given to representatives of Canadian industry dealing with some of the manufacturing and development problems to be encountered in the field of nuclear power. Many examples from Chalk River experience in design and operation of NRX, NRU, etc.*)

J. L. Gray. Presentation to House of Commons Special Committee on Research, AECL-1000, 138 pp., $2.00. (*A complete review of AECL activities prepared for a parliamentary committee.*)

Partial economic study of steam cooled heavy water moderated reactors, AECL-1018, 80 pp., $2.00. (*Even with optimistic assumptions, a steam-cooled D_2O-moderated reactor does not compare favourably with CANDU.*)

Small reactors for northern Canada (prepared for AECL by the Canadian Westinghouse Company), AECL-1045, 31 pp., $1.50. (*Economic studies of PWR and BWR systems in very small sizes for remote locations. Concludes that nuclear power cannot at present compete with oil to meet the demand of the very small communities of the Canadian North.*)

E. C. W. Perryman. A review of Zircaloy-2 and Zircaloy-4 properties relating to the design stress of CANDU pressure tubes, AECL-1048, 34 pp., $1.00. (*Reviews mechanical properties of annealed and cold-worked zirconium alloys and effects of irradiation. Recommends design stress of 17,000 lb/in.^{2} for CANDU pressure tube.*)

—J. E. Woolston, Technical Information Officer, AECL.

Beryllium: Metallurgy of the Rarer Metals, No. 7

By G. E. DARWIN and J. H. BUDDERY (Academic Press, New York, 1960, 392 pages, $13.50)

Reviewed by W. D. BENNETT, Research and Development Laboratories, Canadian Westinghouse Co. Ltd., Hamilton, Ontario, Canada

Starting with the extraction of the oxide from the beryl ore, through purification, metal extraction, consolidation, forming and machining, the book tells a fascinating story of how beryllium metal has been won from the ore and fabricated into usable form despite exceptional technological problems.

As an up-to-date review of past and present beryllium development work, the book comes at a time when a real need has arisen for such a publication in view of the increasing importance of beryllium in nuclear and missile applications. Two particularly valuable features of the book are, first, the numerous graphs and tables recording data in a readily locatable form and, second, the very comprehensive references at the end of each chapter. Both these features will commend the book to the beryllium research worker.

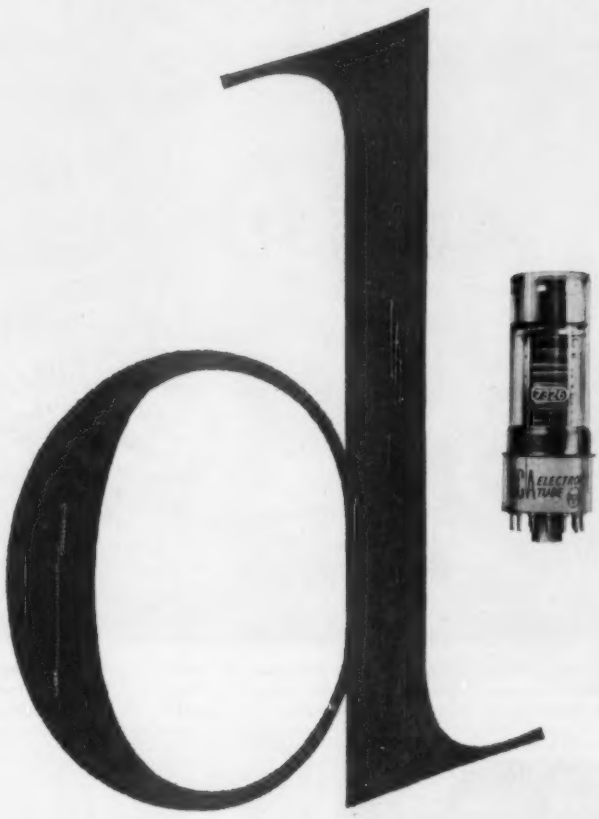
Perhaps, in a book attempting to cover such a broad field, it is inevitable that a few topics should have been neglected, and this appears to be the case in dealing with beryllium metallography. Only a few techniques are mentioned, and a rather poor photomicrograph is used as an illustration.

Although so much work has been

done in developing beryllium, the book points to some weaknesses in our present knowledge of beryllium metallurgy, such as the effects of heat treatment, the role of impurities and the effects of alloying. Appropriately enough, considerable space is devoted to the mechanical properties of beryllium metal and the question of whether or not further purification would increase the ductility. The answer to this question is one upon which metallurgists are unable to agree, some claiming that the metal is intrinsically brittle at room temperature, others suggesting that small percentages of interstitial impurity could be retarding the operation of ductile slip systems. Work on both sides of the Atlantic has been directed at solving this problem by producing high-purity, oxygen-free beryllium using such techniques as distillation and zone refining. At the same time, improvements are being made in the fabrication of currently available metal by careful control of grain size and orientation.

The future of beryllium in the nuclear field depends largely upon its success as a canning material for nuclear fuel, which in turn will no doubt depend to a great extent upon the performance of beryllium cans used in the U. K. Advanced Gas-Cooled Reactor. The behavior of the metal in this reactor will be watched with interest by all concerned with high-temperature, gas-cooled reactors. Beryllium certainly has great potentialities with its low neutron-capture cross section and high-temperature strength, but the conversion of beryllium to helium in a fast-neutron flux presents some problems. Work at Harwell and Chalk River has shown that irradiation below 500° C causes embrittlement due to the production of helium atoms in solution, and, above 600° C, precipitation of the helium in bubbles results in swelling and, in severe cases, permeability to gases. The seriousness of these helium effects will become apparent only after prolonged fuel-element burnup, but there appear to be reasonable experimental grounds for believing that operation at between 500° C and 600° C will be satisfactory. Quality of tube and reproducibility of mechanical properties are other factors that will decide the future of beryllium as a canning material. The minimum ductility and creep strength requirements have no doubt been achieved, but improvements would allow greater versatility in design and increased efficiency of the fuel element.

PERFORMANCE...



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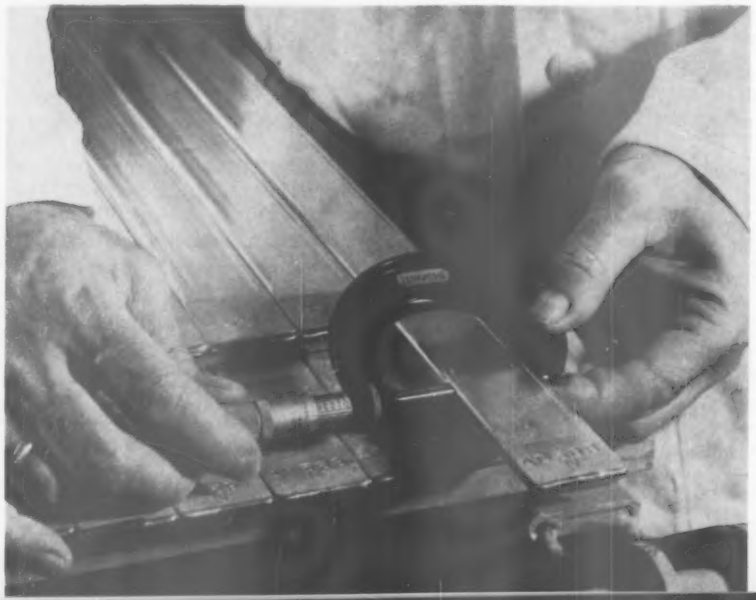
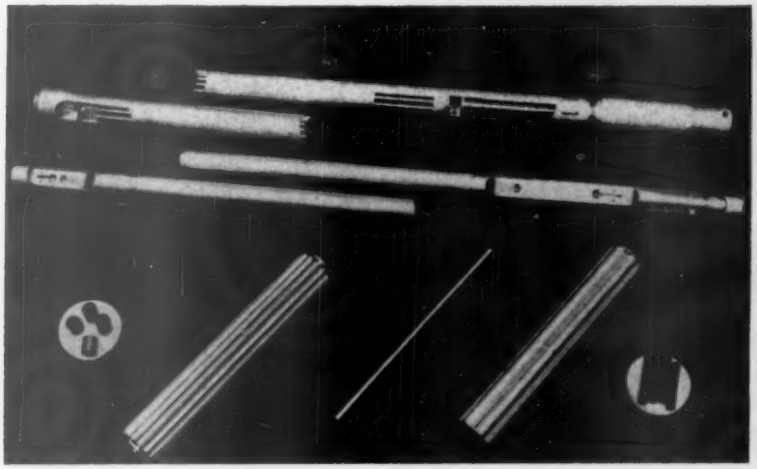
1 MINE. Uranium leaves nature's rugged storehouse at mines like Eldorado's Beaverlodge, Saskatchewan complex. Here at 60° N latitude air strip is sole connection with outside world, except for short summer season when ore goes out by barge. Townsite is in foreground, one minehead and mill are at right center

Canadian Uranium— From Mine to Metal to Fuel

2 METAL. Milled uranium ore is refined and reduced to metal at the Port Hope refinery of government-owned Eldorado Mining and Refining Ltd. Tributyl phosphate extraction is followed by thermal decomposition to uranium trioxide in electric furnaces. UF_4 is produced by a moving-bed process, unique in the field, yielding a large percentage of product at 99% UF_4, which is then reduced with metallic magnesium by the "dingot" process. Dingots are then cast or forged into billets such as shown above

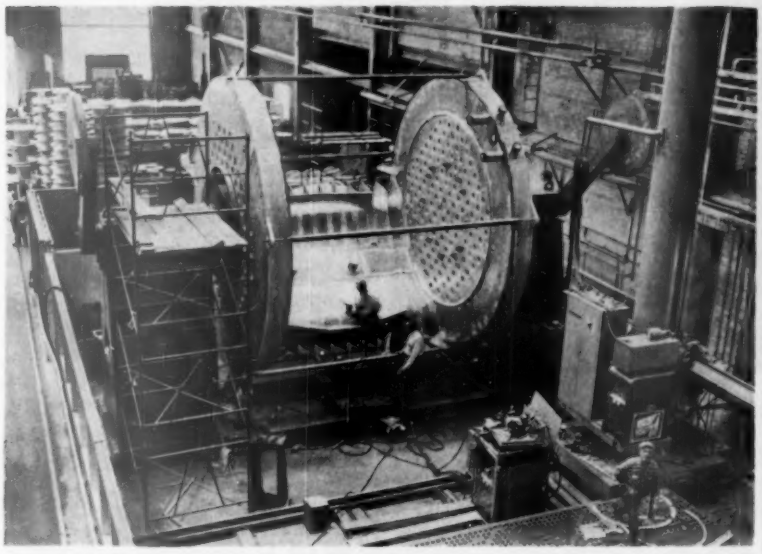
3 FUEL. Metal fuel, like extrusion-aluminum-clad NRU plates shown undergoing final visual and dimensional inspection, is produced at the Port Hope plant of AMF-Atomics of Canada Ltd. Capability extends to uranium-oxide pellets and Zircaloy-clad uranium oxide fuels for power reactors





Nuclear Fuel Fabrication

At Port Hope, Ontario, AMF Atomics has the first Canadian reactor-fuel fabricating plant. The facility is equipped to aluminum-clad uranium metal by extrusion or mechanically; to produce UO_2 pellets with aluminum, stainless-steel or Zircaloy cladding; and to make complete fuel assemblies. It is the exclusive supplier of NRX and NRU fuel, as well as power-reactor-fuel prototypes for testing in ZEEP and ZED-2. Shown above are some of the fuels made (top—sectioned NRU element, Al-clad U plates; next below sectioned NRX element, Al-clad U bar; center—19-rod bundle of UO_2-filled Zircaloy tubes, single tube, 7-rod UO_2-filled Al tube; bottom—UO_2 powder and pellets).—AMF Atomics (Canada) Ltd., Port Hope, Ontario, Canada.



NPD-2 Reactor Calandria

Dump port is shown above being factory-assembled to the NPD-2 calandria end walls. Note the automatic-welding manipulator in right foreground and welding positioner holding calandria sections. Calandria is a double-walled, 44,000-lb vessel of GR40-A-0 aluminum.

Other equipment and services: CGE provides, among its custom-designed products, materials (e.g., special alloys and reactor fuels), reactor components (e.g., vessels and piping) and auxiliary equipment (e.g., reactor fueling machines).—Civilian Atomic Power Dept., Canadian General Electric Co. Ltd., 107 Park St. North, Peterborough, Ontario, Canada.

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Tube type.	9514S	6097S	9536S	9524S
Cathode dia., mm.	44	44	44	23
No. of dynodes	13 Ven. blind	11 Ven. blind	10 Ven. blind	11box/grid
Type	SbCs	SbCs	SbCs	SbCs
Overall Sensitivity, A/L	2000	200	250	200
Dark current, uA	.03	.003	.005	.002

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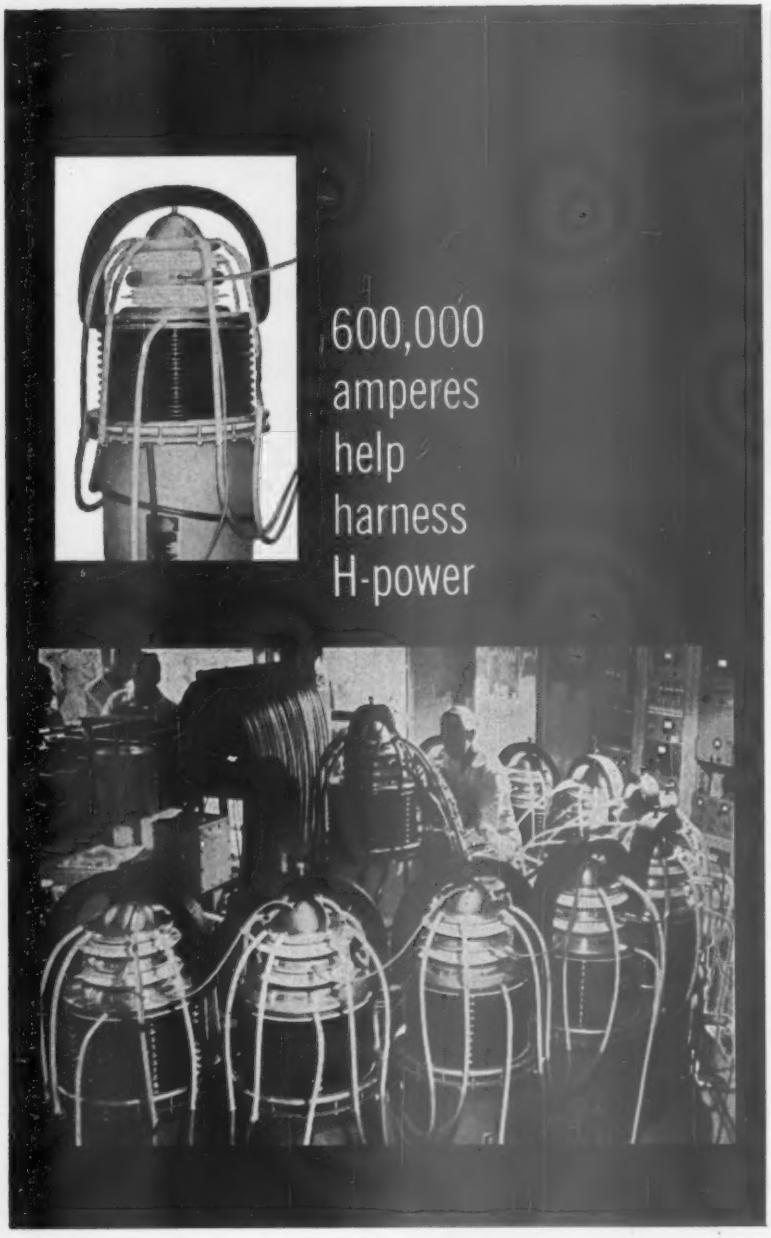

At the historic Geneva Atoms-For-Peace Conference, Los Alamos scientists unveiled **Scylla**—a fusion device used to heat a plasma of ionized heavy hydrogen particles millions of degrees by blasting it with a 600,000-ampere thunderbolt.
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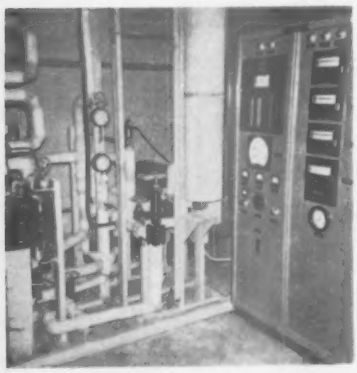
PRODUCTS & MATERIALS

Department starts on page 126



Heat-Transfer Loop

Loop shown above was designed and built for Purdue University for the study of heat-transfer phenomena in forced-convection of light water and in steam generation at 500–2,500 psi. Loop includes electrically heated test section, heat exchangers, pump, deionizer, pressurizer and accumulator. Test-section entry and exit coolant temperatures and pressures and axial temperature distribution along the test section are measured. Burnout alarm and loop trip prevent the section from being accidentally destroyed. The welded test section, a 0.05-in.-o.d., 0.25-in.-bore type 316 stainless-steel tube with conoseal flanges, is rated at 170 kw with a heat flux of 2×10^6 BTU/hr/ft^2 max. Twenty-five thermocouples are spot-welded to the test section over its 4-ft heated length.

Other equipment and services: Complete reactor-system designs, particularly power reactors. Large test-loop-system design and fabrication (in-pile and out-of-pile). Developmental metallurgical programs, e.g., joining materials in reactor vessels and fuels.—Atomic Energy Div., Canadian Westinghouse Co. Ltd., Box 510, Hamilton, Ontario, Canada.

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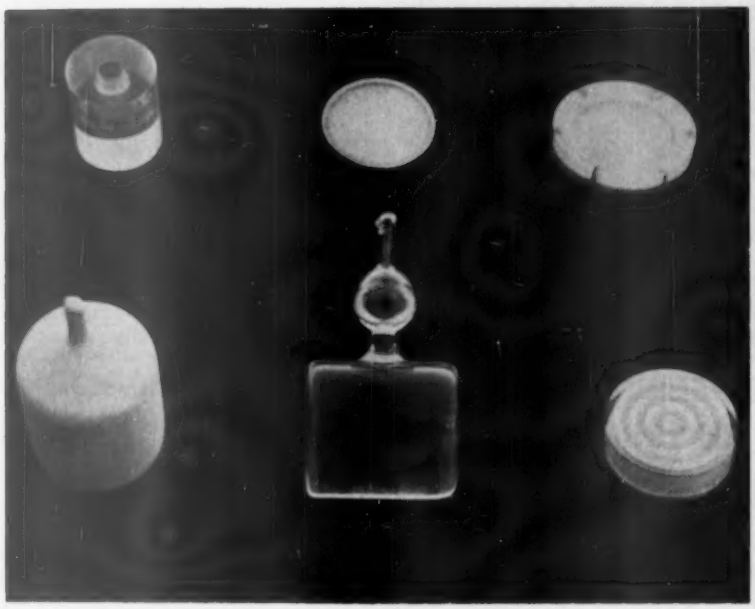
(*Continued on page 130*)

Thorium, Rare Earths

In addition to the large-scale uranium production of the Rio Tinto Group, The Rio Tinto Dow Co. (in equal partnership with the Dow Chemical Co. of Canada) is producing high-quality thorium. An active rare-earth research program of Rio Tinto has resulted in the extraction and sale of the first scandium shipment; work is continuing on extracting other rare earths.—The Rio Tinto Mining Co. of Canada Ltd., 335 Bay St., Toronto, Ontario, Canada.



Liquid, Solid Phosphors

Phosphors shown above (left to right, top row first):

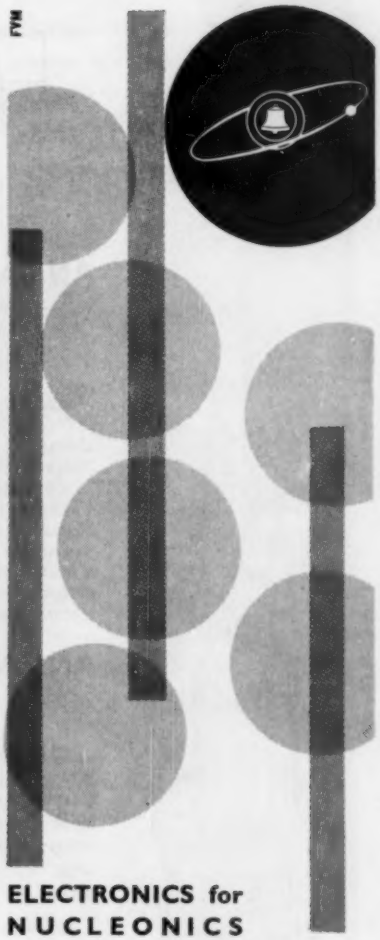
Hollow plastic scintillator (NE812)—Detectors for beta-ray spectroscopy, made from plastic phosphor NE102, are suitable for β-ray energies to <100 kev. Resolution of $\sim$15% was found for Cs^{137} conversion electrons. Designs for specific energies can be produced as requested.

Neutron detectors (NE400, 401, 402)—Active layer of boron polyester and ZnS(Ag), with white reflector, is mounted in clear plastic. Boron is natural (NE400) or enriched (55% B^{10}, NE401; 92%, NE402). Neutron/gamma response of at least 100:1 can be obtained with Po-Be neutrons and Ra or Co^{60} gammas. Detector can be surrounded with paraffin for measuring thermal neutrons.

Capillary-flow counter (NE501)—Plastic-phosphor (NE102) capillary tube (2 ft long, 1.5 mm o.d.) is wound in a spiral, sealed with white reflector and mounted in shallow cup containing silicone fluid. Inlet and outlet connections are provided. Maximum spiral diameter is 1¾ in. and volume is 0.3 cm^3. Detector can be viewed with one or two photomultipliers.

Encapsulated liquid scintillators (bottom, left and center)—Deoxygenated liquids are sealed in glass cells with reservoir of oxygen-free, inert gas. Spray-coated reflector is applied to cell at left.

Fast-neutron detector (NE404)—Detector employs clear-plastic moderator and ZnS(Ag) phosphor. Detection depends on proton recoils in the plastic. White plastic reflector is mounted in the phosphor. Detection efficiency, up to 5%, is made possible by the concentric, cylindrical, clear-plastic light guides that break up the phosphor.—Nuclear Enterprises Ltd., 1750 Pembina Highway, Winnipeg 9, Canada.



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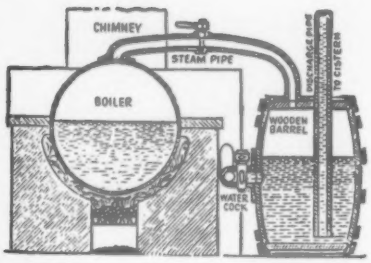
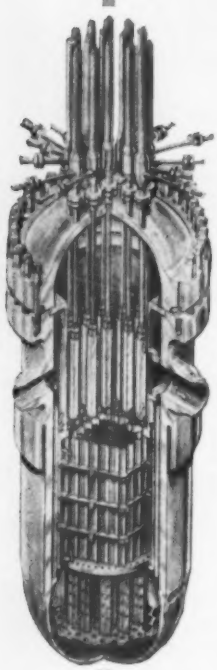


AN ENGINEERING FRONTIER IN 1663...

. . . was finding ways to utilize steam power. In that year, for example, the Marquis of Worcester is credited with inventing the ingenious "steam water lift" shown here. Steam from the boiler passed through a pipe into a wooden barrel. Steam was condensed in the barrel, creating a partial vacuum, which caused water below to rise into the barrel when the water cock was open. When the cock was closed and the steam valve opened, the steam forced the water up through a discharge pipe into a cistern above. It was through trial and error designs like this that the art of steam power generation was first introduced.



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PRODUCTS & MATERIALS

Department starts on page 126

Ltd. of England: type 1532A ionization-chamber dose-rate meter (calibrated up to 500 r/hr, connecting cable, telescopic positioning gear) for indicating radiation level 16 ft from measuring position and for warning system; personnel survey meter (0.1–100 r/hr ± 20%, on/off switch and calibration switch, 2-yr shelf life).

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Other equipment and services: Co^{60} slugs in welded stainless-steel capsules. Source and irradiator design and construction. Consulting, feasibility and cost studies. Gamma-irradiation services. Reactor-produced, unprocessed-target radioisotopes. Irradiation of chemicals, fabricated objects and working experiments. Cs^{137} and Co^{60} radioteletherapy units.—Commercial Products Div., Atomic Energy of Canada Ltd., Box 93, Ottawa, Canada.

Semiconductor Detectors

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LITERATURE AVAILABLE

Industrial uses of gamma rays . . . a bibliography—9 pp.
Radioisotopes, what they are and how they are produced—20 pp.
Atomic Energy of Canada Ltd., Commercial Products Div., Box 93, Ottawa, Canada

Radiation meter—4 pp.
Radiation Recording Instruments Co., Box 1056, Station B, Montreal 2, Canada

Canada's first fuel facility—12 pp.
Experienced management—4 pp.
AMF Atomics Canada Ltd., Port Hope, Ontario, Canada

R.F. noise probe—4 pp.
Nash and Harrison Ltd., 1355 Wellington St., Ottawa, Ontario, Canada

Geartight self-locking camtight plug—4 pp.
Some applications of the Geartight union—12 pp.
United Flexible Metallic Tubing (Canada) Ltd., Centre St. East, Box 504, Richmond Hill, Ontario, Canada

Patents handbook—100 pp.
Canadian Patents and Development Ltd., National Research Building, 100 Sussex Drive, Ottawa, Canada

NPD-2 design description—27 pp.
Ceramic fuel for reactors—6 pp.
Nuclear components—6 pp.
Organic-cooled D_2O reactor—6 pp.
Civilian Atomic Power Dept., Canadian General Electric Co. Ltd., Peterborough, Ontario, Canada

Catalog of uranium products—20 pp.
Eldorado Mining and Refining Ltd., Sales Office, Port Hope, Ontario, Canada

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INSTRUMENTATION AND MEASUREMENTS

This article starts on page 82

Time can be introduced by starting the display and allowing it to go quickly through the events stored on the drum. On the first readout the oldest information in each address will be presented, on the next readout the oldest but one, and so on until the present is reached. A large amount of information will be quickly conveyed in this manner, not in detail perhaps, but trends will be seen which should indicate where detail should be sought. The display can of course be repeated as often as required. We are attempting to do electronically what is done photographically when, for example, the details of plant growth are quickly recreated.

The experimental system being developed is shown in Fig. 3. A solid-state electronic scanning system samples each transducer in turn so that every variable is represented by an electrical pulse. Scanning takes place at maximum levels of 100 mv or 50 μamp and the time for each measurement is 500 μsec. Temperature-sensitive resistance bulbs, however, are scanned by pulsing the drive to the appropriate bridge. The pulse representing each measurement is amplified, converted to binary-code form and held in a temporary store. The information is then transferred onto the rotating drum and the scanner moves on to the next-in-line transducer.

The display equipment is separate from the data-writing system. It is shown at the bottom of Fig. 3. The address number positions the trace on the cathode-ray-tube screens. The magnitude of the variable further adjusts the position of the trace for the amplitude-time display, and the intensity for the geometric display. Both pictures change in real time, but the geometric display can be programmed to scan the stored data at a selected rate.

The signal scanning and digitizing equipment is typical of the most recent innovations in data handling. Further, by using a magnetic drum to store data continuously it becomes relatively simple to add a variety of displays.

The experimental system uses standard Chalk River circuit board techniques. When the components are assembled, where the 32 temperature-sensitive resistors are connected to the scanner by a 500-foot length of multicore cable.

Nuclear Activities at Universities

The achievements in the nuclear field recorded elsewhere in this issue stem in good part from the excellent universities in Canada. Listed here are those that have special courses and/or facilities in the nuclear field. This listing is based upon a survey conducted by O. J. Hahn and W. James Slater, graduate students at West Virginia and McMaster Universities, respectively. All of the universities offer work in nuclear physics, but we have noted especially here the few who have programs in nuclear engineering. The number of faculty members associated with nuclear programs was variously interpreted and is only a rough index of the importance of nuclear activities. Only the most major facilities have been noted; most of the schools have such ancillary equipment as digital and analog computers. particle and gamma-ray spectrometers, counting equipment, etc.

Nuclear Programs at Canadian Universities

University	*Nuclear engineering degrees**	*Faculty*	*Special facilities*
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Dalhousie Univ., Halifax N. S. Prof. E. W. Guptill, Head, Dept. of Physics			
McGill Univ., Montreal, P. Q. Dean D. L. Mordell, Faculty of Engineering	X	1	100-Mev synchrocyclotron 10-Mev linear accelerator
McMaster Univ., Hamilton, Ont. Prof. J. S. Kirkaldy, Dept. of Metallurgy & Metallurgical Engineering	M	5	1-Mw swimming-pool
Queen's Univ., Kingston, Ont. Prof. B. W. Sargent, Head Dept. of Physics	B	3	70-Mev synchrotron
St. Francis Xavier Univ., Antigonish, N. S., Rev. E. M. Clarke, Dept. of Physics		2	
Univ. de Montreal, Case Postale 6128, Montreal, P. Q., Dr. Paul Lorrain, Dir., Dept. of Physics		7	500-kev Cockcroft-Walton
Univ. of Alberta, Edmonton, Alta., Prof. H. Grayson-Smith, Head, Dept. of Physics	X	3	2-Mev Van de Graaff
Univ. of British Columbia, Vancouver, B. C., Prof. G. M. Shrum, Head, Dept. of Physics		20	2.25-Mev Van de Graaff
Univ. de Laval, Quebec, P. Q. Prof. E. Geoffrion		3	5.5-Mev Van de Graaff
Univ. of Ottawa, Ottawa, Ontario, Dean P. R. Genron, Faculty of Pure Appld. Sci.	M	9	
Univ. of Saskatchewan, Saskatoon, Sask., Prof. B. W. Currie, Head, Dept. of Physics		4	Subcritical assembly
Univ. of Toronto, Toronto, Ont. Prof. R. E. Jervis, Chem. Eng.,	B X	4	3-Mev Van de Graaff
Univ. of Western Ontario, London, Ont., Prof. E. Brannen		2	4-Mev microtron

*B = B.S., M = M.S., P = Ph.D., X = as minor in other dept.

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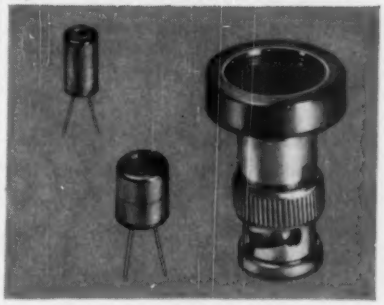

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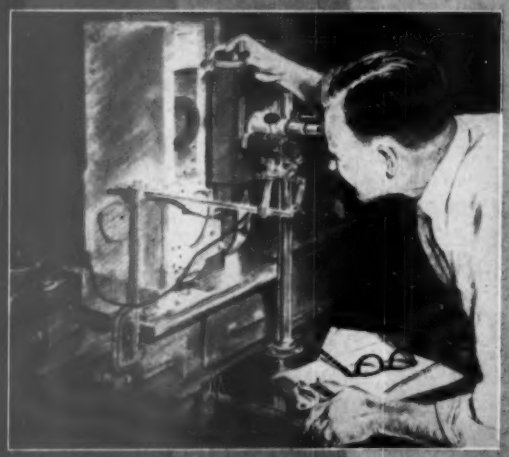

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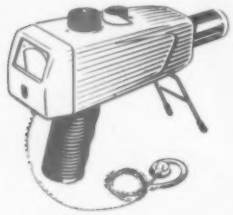

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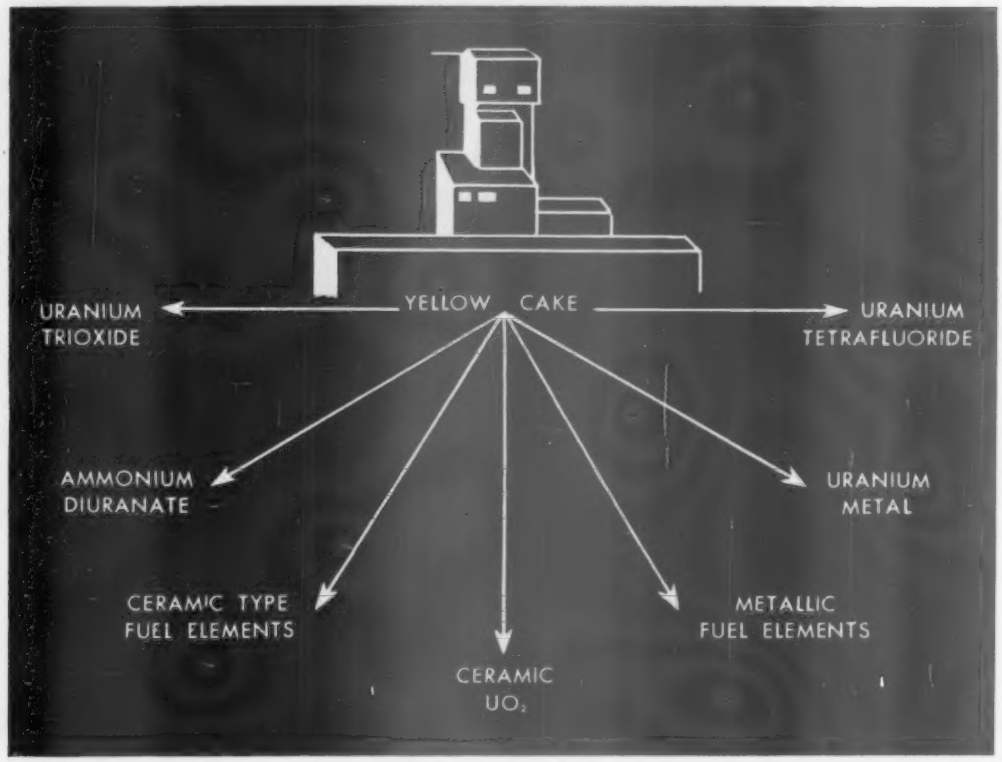

TYPICAL CERAMIC UO_2 ANALYSIS

CHEMICAL	SPECTROGRAPHIC				
Fe ....25.0 ppm	Ag ....0.1 ppm		Mn ... 2.0 ppm		
Mo 0.5	B 0.15		Cu ... 1.0		
	Cr 5.0		Ni ... 5.0		
	Cd 0.1		Si 15.0		
	Dy 0.05		Gd ... 0.02		

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ATOMS AT WORK in the Americas

The peaceful uses of the atom—for medicine, agriculture, electric power, and marine propulsion—are featured in the Atomic Energy Commission's *Atoms at Work* exhibition, which begins a year-long tour of South America in November. It will first be shown at the Argentine Sesquicentennial Exposition in Buenos Aires. The *Atoms at Work* exhibit features a Lockheed-built nuclear reactor—a relatively high-powered training reactor capable of performing a wide range of experiments and demonstrations. Lockheed Nuclear Products designed and fabricated this pool-type reactor so that it can be easily transported. The entire reactor—control rod drives, instrumentation system, and console—can be shipped in compact units. *Address: 3272 Peachtree Road, N.E. Atlanta 5.*

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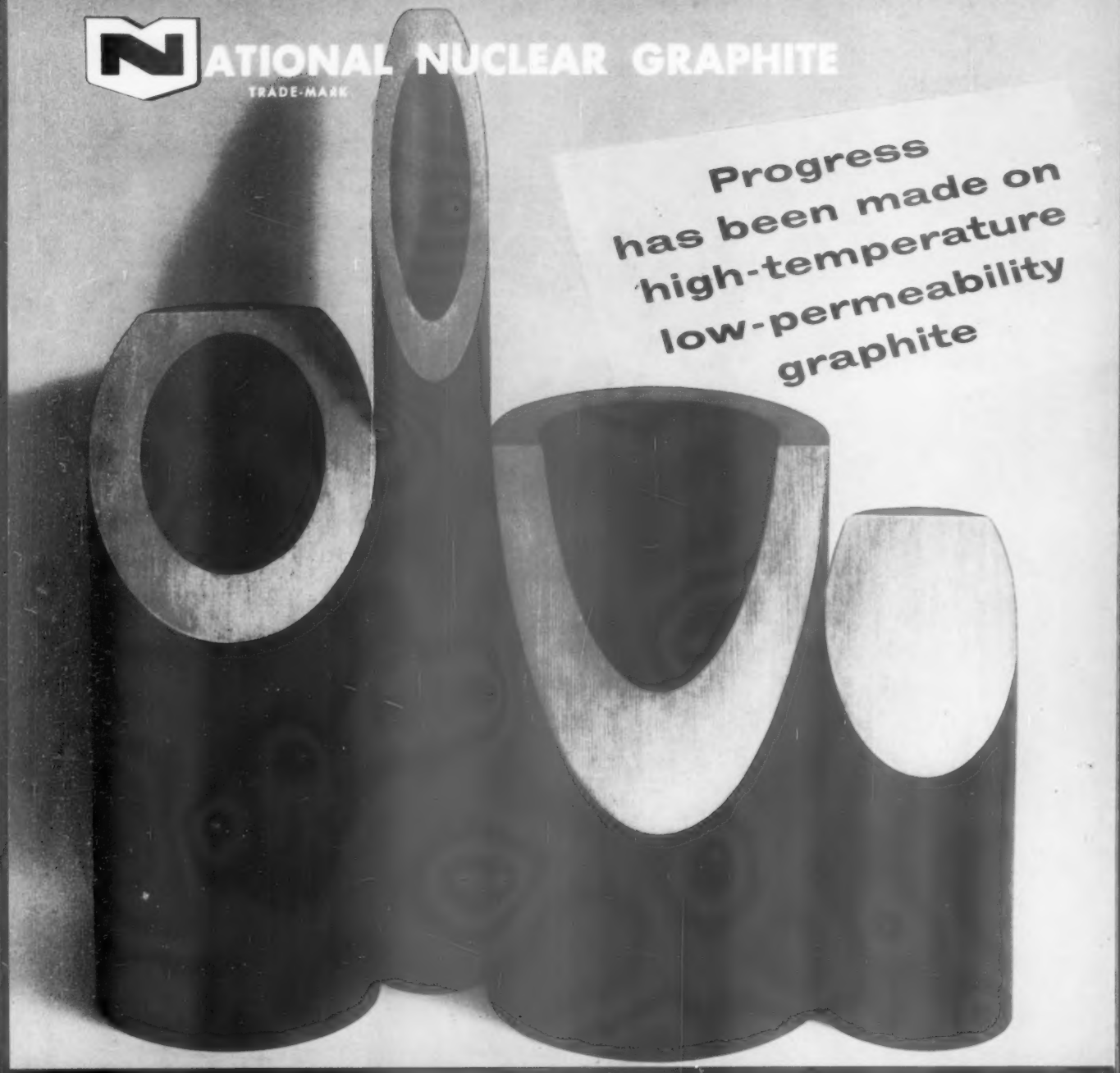

Today's growing interest in higher and higher temperature reactor concepts has increased the critical demand for specialized structural materials. National Carbon Company's current development work has proved that 10' long tubular graphite can be produced with a helium admittance of 10^{-7} cm^2/sec. STP (standard temperature and pressure). Actually, experimental work in the laboratory has produced graphite with lower permeability.

This fully graphitized material has been processed at temperatures well over 2500° C. ***Low permeability is achieved throughout the material and is not just a result of a surface condition.***

Presently, irradiation results are most encouraging. Specific data are still being accumulated. There are irradiations in process of graphite matrix fuel bodies encapsulated in this low permeability graphite. Fission product release data are being determined.

While considerable effort is still required to reduce manufacturing time, National Carbon Company, through its research, development and production departments is working towards satisfying the nuclear industry's special requirements for graphite. National Carbon Company, Division of Union Carbide Corporation, 270 Park Avenue, New York 17, N.Y. In Canada: Union Carbide Canada Limited, Toronto.

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